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GEOLOGY OF THE MIDDLE MEMBER OF THE BAKKEN FORMATION IN DIVIDE COUNTY, NORTH DAKOTA

Mandy Brewer
Montana Tech

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by

Mandy Brewer

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Abstract

The Upper Devonian-Lower Mississippian Bakken Formation of Williston Basin is a large unconventional oil and gas play consisting of a lower shale member, a middle member, and an upper shale member. The middle member is a production target because it contains porosity and petroleum expelled from the shale members around it. Variable production and sweet spots of the Bakken in the study area of Divide County, ND and 15 miles around Divide County in the USA prompted a closer look at middle member Bakken sediments. For this study, 606 wells were correlated and thin sections from two wells located 10.17 miles apart were point counted for mineralogy, grain size, and grain angularity, as well as analyzed for types of cements and diagenetic features using a scanning electron microscope. Minor variations in mineralogy, grain size, and grain angularity indicate similar depositional environments between the two wells. Similar dolomite cement compositions between the two wells indicate that the same fluids and diagenesis occurred in both well localities. The Bakken Formation locally thickens where underlying Prairie Formation evaporite locally thins, indicating that the evaporite underwent dissolution during lower shale and middle member Bakken deposition. The Bakken middle member clean sand (clean gamma ray response) facies and overlying facies correlate well across the study area, while underlying facies are heterogeneous and too variable to correlate across the study area.

Keywords: Bakken Formation, Williston Basin, Divide County, Geology, Mineralogy

Dedication

I would like to recognize and thank my parents for their financial support, encouragement, and advice during my schooling. I would also like thank my twin sister Melanie for her exceptional encouragement, support, and understanding in all aspects of life. She is the absolute best. Thank you to the Sorenson family for adopting me into your Montana family. This would not have been possible without you guys.

Acknowledgements

I would like to thank my advisor Dr. Larry Smith for all of his guidance and help, Dr. Michael Hofmann from Montana State University for helping me with SEM work and for being a sounding board, and Sarah Edwards (current employee) and Riley Brinkerhoff (former employee) of SM Energy Company for providing data, ideas on thesis topics, and feedback. I would also like to thank Dr. Chris Gammons and Assistant Professor David Reichhardt for their help as the graduate committee.

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1. Introduction

The Williston Basin is a large intracratonic basin located mainly in North Dakota, Montana, and Saskatchewan, with small parts in South Dakota, Manitoba, and Alberta (Figure 1). The basin's Late Devonian-Early Mississippian Bakken Formation is an unconventional oil and gas play with an estimated mean of 3.65 billion barrels of undiscovered, technically recoverable oil resources (Gaswirth et al., 2013).

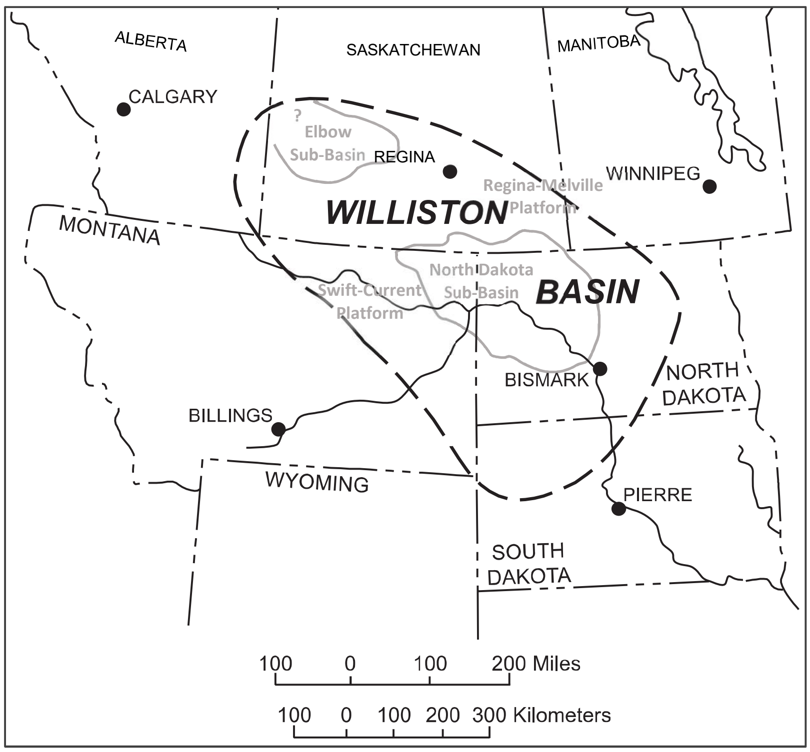


Figure 1. Extent of the Williston Basin (modified from Pitman et al., 2001). Sub-basins and platforms approximately drawn in from Smith and Bustin (1997).

The Bakken Formation overlies the Devonian Three Forks Formation, is overlain by the Mississippian Lodgepole Formation, and consists of an upper and lower shale member separated by a middle member. The lower and upper shales expelled hydrocarbons through vertical fractures caused by fluid overpressuring from organic matter volume expansion during hydrocarbon generation (Price and LeFever, 1992). These fractures allowed migration of hydrocarbons into the middle member as well as the adjacent uppermost Three Forks and lowermost Lodgepole formations (Price and LeFever, 1992). The middle member is the target for oil and gas production because it contains porosity, micro porosity, and petroleum expelled from the shale members above and below it.

The Bakken Formation has variable production of zero to 1,000 barrels of oil per day in the first 60 days of production within the study area of Divide County, North Dakota and 15 miles around the county in the USA (Figure 2). At this time, no detailed geologic studies have been completed in Divide County. SM Energy Company expressed interest in learning more about depositional environments and diagenesis as they are possible factors controlling the variable production and sweet spots in Divide County. SM Energy provided access to core and thin sections for their Torgeson 2-15HS and Tomlinson 3-1HN wells, core descriptions for these

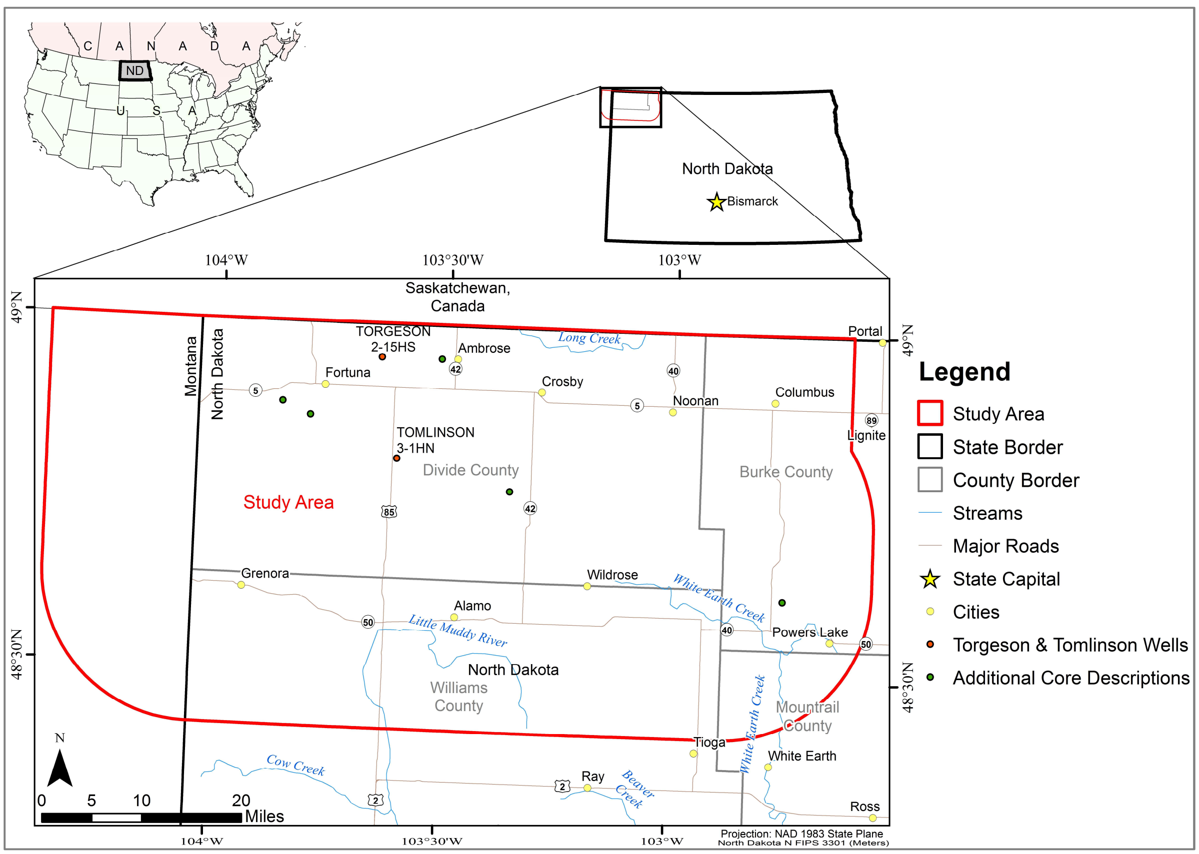


Figure 2. Study area of Divide County, North Dakota and 15 miles around Divide County in the USA.

two wells and five additional wells, and some X-ray diffraction data (XRD) in Divide County for this thesis. Studying the mineralogy, grain size, grain angularity, facies, and facies thicknesses in the middle member may provide insight and clarification for current depositional environment theories and factors controlling sweet spots.

1.1. Statement of Purpose

The primary objectives of this thesis are to explain the variations in lithology and thicknesses, and determine the diagenesis of the middle member of the Bakken Formation in Divide County, ND and 15 miles around Divide County in the USA. Questions addressed in this thesis are:

- Does grain lithology or size change between wells? What does this imply about source, distribution, and deposition of sediments?
- What types of cements are there and what are their relative relationships to each other? Is cementing localized well-to-well or on a larger scale?
- Do Bakken Formation thicks coincide with Prairie Formation evaporite thins?
- Are the middle Bakken facies correlative throughout the county? If not, what are the reasons and implications?
- What do thickness changes in the upper and lower shale member show?
- What do thicknesses of facies within the middle member show?

1.2. Previous Work

Due to the ongoing importance of the Bakken Formation to the oil and gas industry, studies of organic shale, structure, and stratigraphy have continued for over 60 years. Development of thought on facies and depositional environment of the middle member of the Bakken Formation is shown in Figure 3.

	Author	Nordquist (1953)	Christopher (1961)		Thrasher (1987)		Smith & Bustin (1997)		Pitman et al. (2001)		LeFever (2007)		Hofmann et al. (2014)	
	Study Area		Southern Saskatchewan (Elbow sub-basin facies)		North Dakota		Manitoba, Saskatchewan, North Dakota (facies for ND)		North Dakota		North Dakota		Divide County, ND (Tomlinson 3-1HN facies)	
Bakken Formation	upper member	Shale	Shale	Swamp-lagoon	Shale		Shale	Distal, deep marine water	Shale	Offshore Marine	Shale	?	Shale	Shelf suspension settle, episodic event dep, anoxic-dysoxic
	middle member	Sandstone	B4: Silty SS & cg ST	Regressive	3: ST, more defined bedding	?	Msh: Mudstone, well to poorly defined laminations	Offshore	7: ST	Marine environment with strong current action	5: ST to carbonate	Middle-Lower Shoreface	8: Bioclastic muddy ST	Offshore Transition
											4: SS, ST, claystone, SH	Lower-Upper Shoreface	9,9.1: Bioturb Interbedded MD-SS/MD & SS	Offshore Transition
			B3: Laminated SS & SH	?	2: Beds of SH, SS & SS with scour, cross-bedding, ripples	Transgressive	St: fg-mg SS Tabular cross beds, flat non-parallel low angle sfcs	Upper Shoreface	5&6: Parallel interbedded SH & silty SS	?	3: Vfg-fg SS to LS	Middle-Lower Shoreface	11: Parallel laminated Silty SS	Offshore Transition
													12.1: Parallel laminated SS	Middle
													12.2: Bioturb SS	Lower Shoreface
			B2: SS w/ cross-bedding, scours, ripples				Msh: Mudstone, well to poorly defined laminations	Offshore	3&4: SS trough & tabular cross-bedded	Tidal Channels	CBF: Basal SS, ST, SS with claystone, and upper ST with vfg SS	Middle Shoreface	12: Ripple cross-laminated ST & Silty SS	Shoreace above fair-weather wave base
													11.1: Micro cross-laminated ST & silty SS	Offshore Transition
													11: Parallel laminated silty SS	Offshore Transition
			B1: Shale		1: Fossiliferous bioturbated pyritic ST to dolomite to silty LS	Regressive	MSm: Mudstone, massive, burrowed	Offshore	2: Parallel interbedded SH and silty SS	Lower shoreface	2: ST to vfg SS	Upper-Lower Shoreface	10: Bioturb ST	Offshore Transition
			A: Vfg to silty SS (fossiferous, pyritiferous)						1: Siltstone	Shallow Water Offshore Marine	1: LS & ST	Upper-Lower Shoreface	8: Bioclastic muddy ST	Offshore Transition
	lower member	Shale	Shale	Swamp-lagoon	Shale	?	Shale	Distal, deep marine water	Shale	Offshore Marine	Shale	?	Shale	Shelf suspension settle, episodic event dep, anoxic-dysoxic

Figure 3. Development of thought on facies and depositional environments for the middle member of the Bakken Formation. SH=shale; SS=sandstone; ST=siltstone; LS=limestone; vfg=very fine-grained; fg=fine-grained; mg=medium-grained; cg=coarse-grained; sfcs=surfaces. This figure is my interpretation of how different authors' facies correlate to each other. Numbers are the various authors' naming conventions for lithology of the middle member.

Nordquist (1953) defined the Bakken Formation and named three informal members: the upper and lower shales and a middle sandstone member. Sandberg and Hammond (1958) re-interpreted the age of the Bakken to be Devonian-Early Mississippian. They divided the Bakken Formation into two black shales separated by a middle sandstone, siltstone, or dolomite.

Christopher (1961) recognized that the Bakken Formation in southern Saskatchewan also includes upper and lower shales with a middle sandstone member. He subdivided the middle sandstone member into a unit A and unit B. Basal unit A is massive, pyritiferous, fossiliferous, very fine grained to silty sandstone. The unit is believed to be absent over the Regina-Melville platform in Saskatchewan (Figure 1) and extreme eastern shelf area, probably due to erosion (Christopher, 1961). Unit B is an alternating and interfingering shale-sandstone unit. Lower shale member black muds imply restricted circulation of a fairly oxygenated sea. The initial middle Bakken transgression brought the eastern shore to a line somewhat east of the lower Bakken shale edge. Silt and clay from the northwest and east filled the deeper basinal areas of the southeast, west, northwest, and north. After deposition of the basal unit A, the eastern area began to subside, water over the Regina-Melville platform deepened, and the sea spread over the shelf to the east. Sand supply entered the southern, western, and northwestern parts of the area intermittently, thereby depositing unit B of mud laminated with cross-bedded and channeled fine sands. These sediments suggest a sea-floor of tidal flats, lagoons, hollows, and shoals traversed by currents. Near the end of middle Bakken time, a slow regression deposited a thin layer of silt and very fine sand over the area. As overall depth decreased, sedimentation reduced to generation of black mud in repetition of the lower Bakken swamp-lagoonal environment.

Sandberg (1961) reviewed Devonian rocks in the Williston Basin, central Montana, and north-central Wyoming. He briefly discussed structures that were active during the Middle to

Late Devonian. He also discussed the Three Forks Formation in some detail and noted the fine-grained sandstone 5-15 ft thick at the top of the formation near Nesson Anticline that was informally known as the Sanish sand at the time.

Ettensohn and Barron (1981) studied the tectonic setting and paleoclimatology of Devonian-Mississippian shales in North America. They described that in enclosed seas with a large fresh-water influx, the lighter fresh or brackish water floats above the saltier normal seawater, which can prevent normal vertical circulation and lead to loss of bottom oxygenation. This loss leads to accumulation of black, organic-rich muds. Lateral mixing of waters in enclosed seas with open marine waters can be prevented by a barrier or by the anaerobic bottom waters being restricted to an individual basin.

Hayes (1985) described the Bakken Formation and used conodonts from 17 cores in Williston Basin to report conodont diversity in the formation. He divided the Bakken into two shales separated by a dolomitic-sandstone and fine-grained sandstone. The lower shale and middle member were assigned as Late Devonian (Famennian age) and the upper shale was assigned as Early Mississippian (Kinderhookian age). A hiatus exists between the middle member and upper shale member. Shales were deposited in anoxic, offshore environments during episodes of widespread marine transgression. The middle member was deposited in a current-influenced, mostly aerobic marine environment during a time of marine regression.

Thrasher (1987) studied macrofossils and stratigraphy of 39 Bakken cores in North Dakota. He found eleven new types of brachiopods and used the macrofossils to re-define units within the middle member and to correlate with contemporaneous conodont zones in Utah, Montana, Alberta, and South Dakota. He divided the Bakken Formation into an upper and lower shale with a middle member split into three units.

Lindsay et al. (1988) studied the structural history and characteristics of the Nesson Anticline in North Dakota. Karma and Parslow (1989) studied the geochemistry of the Bakken shales in southern Saskatchewan.

Richards (1989) discussed the upper Kaskaskia sequence in Canada and in the Williston Basin. Proposed distal sources of sediments were the Acadian Mountains to the east and cratonic highlands to the north and northeast. Proposed marginal sources were the Antler, Caribou, and Ellesmerian mountains to the west and the north.

Smith and Bustin (1997) studied 189 core intervals intersecting the Bakken Formation in Manitoba, Saskatchewan, and North Dakota. The core information was used in conjunction with thin section analysis, X-ray diffraction, and Rock-Eval analysis from previous authors to create structure maps, isopach maps, and stratigraphic cross sections using 1,800 wells. Structure maps of Upper Devonian formations beneath the Bakken Formation show two sub-basins: the Elbow and North Dakota sub-basins, which are separated by the Regina-Melville and Swift Current platforms. Smith and Bustin (1997) also separated the middle Bakken Formation into eight lithofacies. The well in North Dakota that was selected as a “typical” North Dakota well had three of these lithofacies.

Smith and Bustin (1998) proposed an estuarine-like marine circulation between the Williston Basin and open-ocean conditions at the western craton edge of North America. The paper only divided the Bakken Formation into an upper and lower hemipelagic black mudstone separated by a middle mudstone/siltstone member. The middle mudstone/siltstone member was split into three layers.

Pitman et al. (2001) studied diagenesis and fracture development in the middle member using 40 sandstone samples obtained from drill core. Their sample locations are in Figure 4.

Pitman et al. (2001) created the chart in Figure 5 explaining middle Bakken postdepositional events.

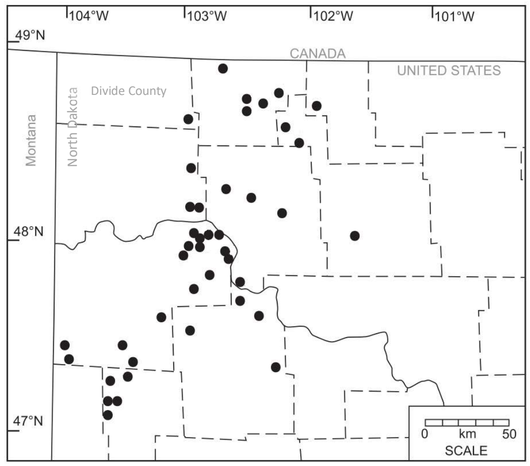


Figure 4. Locations of drill core samples for petrographic and geochemical analysis (modified from Pitman et al., 2001).

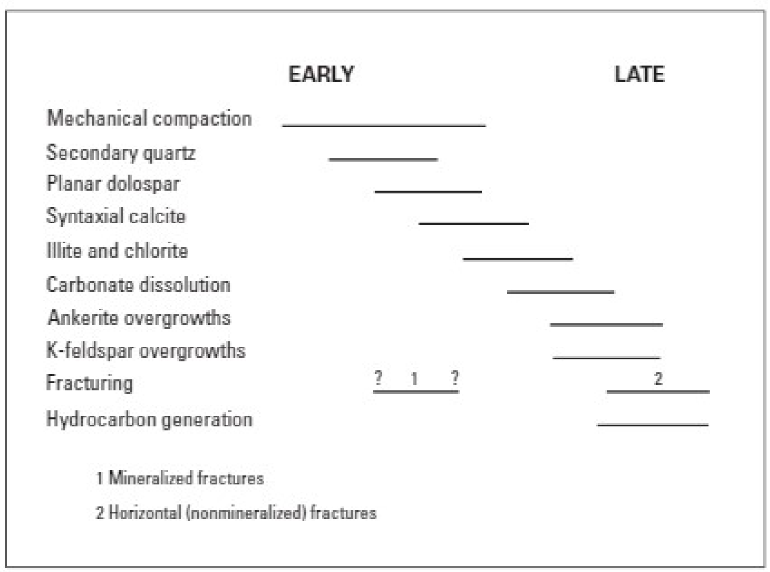


Figure 5. Postdepositional events in the middle member of the Bakken Formation (Pitman et al., 2001).

LeFever (2007) divided the middle Bakken in Williston Basin into six lithofacies and described them through a series of maps. LeFever (2007) also mentioned sediment supply direction, impact of the Nesson Anticline on sedimentation, and salt dissolution of the underlying Prairie Formation evaporite.

Angulo and Buatois (2009) divided the middle Bakken in southeastern Saskatchewan into 11 lithofacies grouped into two facies associations of open marine and brackish-water marginal marine. Anna et al. (2010) studied the geologic framework of the Williston Basin and gave guidelines used in the USGS assessment of oil and gas resources. Canter et al. (2011) divided the middle member of the Bakken Formation in Parshall and Mountrail counties of North Dakota into five facies A-E. Egenhoff et al. (2011) used 31 cores in Williston Basin to reconstruct fine-scale architecture of the Bakken Formation. He divided the formation into eleven facies.

LeFever et al. (2011) proposed that the formerly known “Sanish sand” interval of the Three Forks Formation be assigned to the Bakken Formation and given the name Pronghorn member. The United States Geological Survey (USGS) has not recognized the Pronghorn as a formal member of the Bakken Formation at this time.

AIM GeoAnalytics described thin sections and core in the Bakken and Three Forks formations for SM Energy’s Torgeson 2-15HS and Tomlinson 3-1HN wells located in Divide County, ND (Hofmann et al., 2014). The middle member of the Bakken Formation was divided into nine lithofacies (Figure 6; Hofmann et al., 2014).

Gaswirth and Marra (2015) for the USGS 2013 assessment of resources in the Bakken and Three Forks formations of the U.S. Williston Basin Province divided the formations into petroleum assessment units further than the assessment published in 2013. They followed LeFever et al. (2011) in classifying the formerly known Three Forks “Sanish sand” as the Pronghorn member of the Bakken Formation.

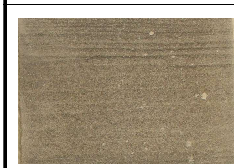
Hofmann et al. (2014)			
Lithofacies			Interpretation
	8	Bioclastic Muddy Siltstone	Offshore transition zone; high biologic activity; influx of bioclastic material
	9	Bioturbated, Interbedded Mudstone-Sandstone	Offshore transition zone; periodic biologic activity; episodic storms
	9.1	Bioturbated Interbedded Sandstone & Mudstone	Offshore transition zone; periodic biologic activity, higher frequency of storms than 9
	10	Bioturbated Siltstone	Offshore transition zone; relatively low energy; high activity
	11	Parallel Laminated Silty Sandstone	Offshore transition zone; low to no biologic activity
	11.1	Micro Cross-Laminated Siltstone & Silty Sandstone	Offshore transition zone; episodic deposition and biologic activity
	12	Ripple Cross-Laminated Sandstone	Shoreface above fair-weather wave base
	12.1	Parallel Laminated Sandstone	Middle shoreface; rapid sedimentation
	12.2	Bioturbated Sandstone	Lower shoreface; moderate biologic activity

Figure 6. Hofmann et al. (2014) facies of the middle member of the Bakken Formation.

2. Geologic Setting

2.1. Paleogeography

North America during the Late Devonian-Early Mississippian was located approximately 5-10° north of the equator (Ettensohn and Barron, 1981; Smith and Bustin, 1998) and was covered largely by shallow waters of the Devono-Carboniferous North American Seaway (Figure 7 and Figure 8; Algeo et al., 2007). The climate was tropical to savannah-like with seasonally wet and dry conditions (Smith and Bustin, 1998).

2.2. Plate Tectonics

Four orogenies during the Devonian formed the mountains and highlands in Figure 7. These mountain building events are possible sources of sediments. The Caledonian Orogeny during the Late Silurian to earliest Devonian resulted from collision of the Baltic Shield (Baltica) with North-American Greenland (Laurentia) and formed the Caledonides to the far north and northeast of the Williston Basin. The new land mass, including the present day North America, Greenland, Scotland, Scandinavia, and England (Cocks and Torsvik, 2011), was called Laurussia (Ettensohn and Barron, 1981). The Acadian Orogeny during the Middle Devonian resulted from collision of a Baltica peninsula with Laurussia and formed the Acadian mountains along the eastern side of Laurussia. The Baltica peninsula was pushed north into Laurussia by north-western South America, also known as Gondwanaland (Ettensohn and Barron, 1981). The Ellesmerian Orogeny from Middle Devonian to earliest Mississippian resulted from an oblique plate collision between two continental crusts that rifted in the Cambrian. The collision formed the Ellesmerian Mountains that extend from northern Greenland to northern Yukon (Embry, 1988). The Antler Orogeny during the Late Devonian resulted from older Devonian and underlying oceanic rocks being deformed and obducted eastward onto the western margin of the craton. This movement formed the Antler Mountains to the west of the Williston Basin (Ettensohn and Barron, 1981).

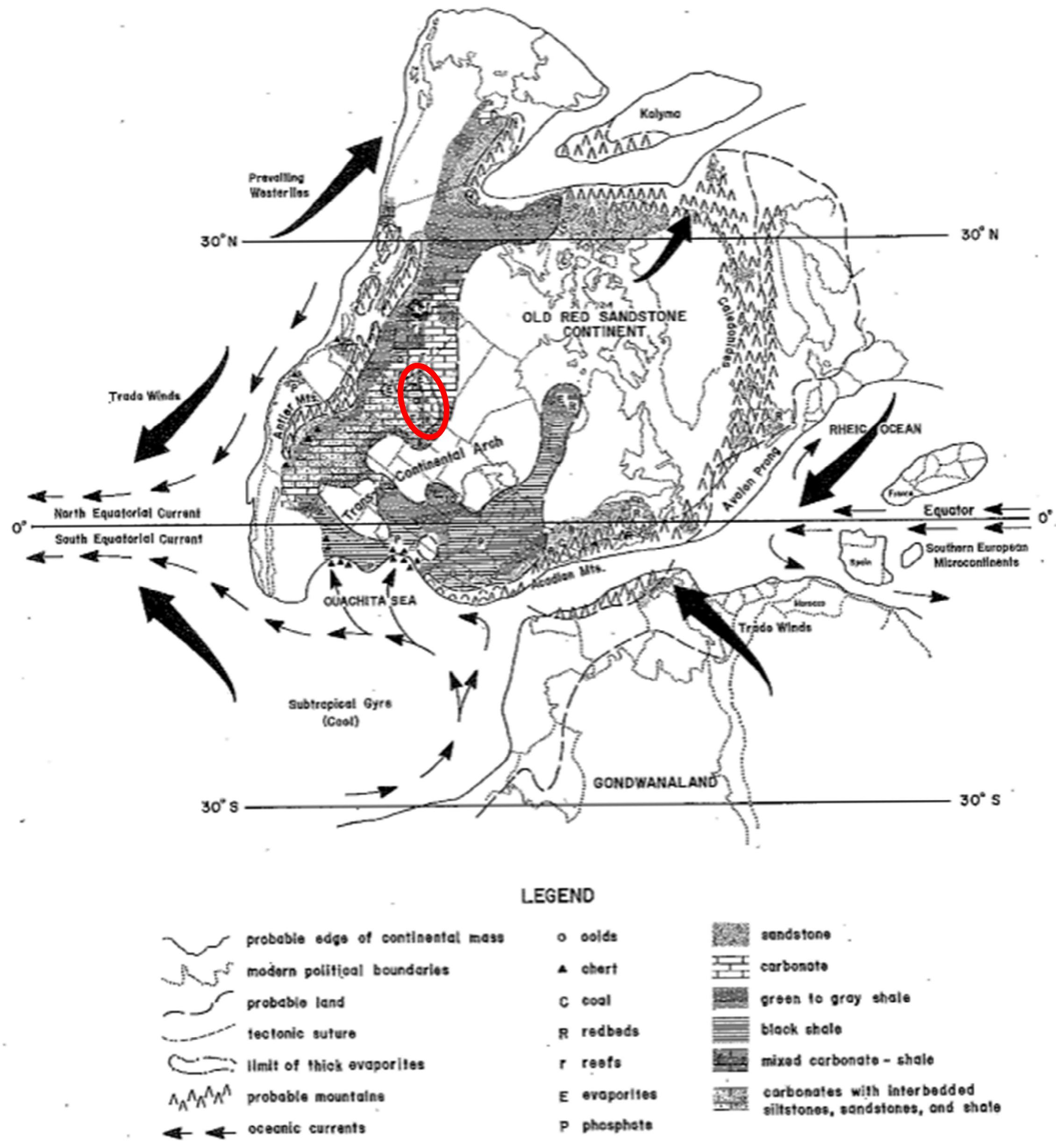


Figure 7. Generalized Late Devonian paleogeography and lithofacies of North America (modified from Ettensohn and Barron, 1981). Approximate location of Williston Basin is outlined in red.

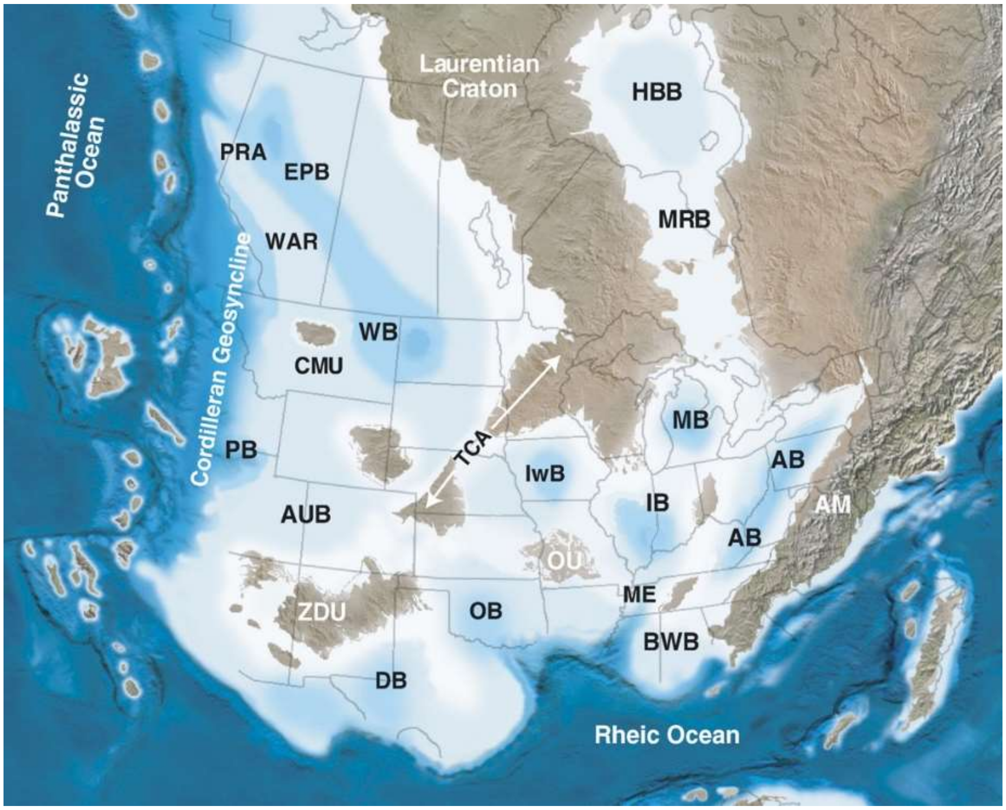


Figure 8. Late Devonian paleogeography of North America. AB=Appalachian Basin; AM=Appalachian Mountains; AUB=Ancestral Uinta Basin; BWB=Black Warrior Basin; CMU=Central Montana Uplift; DB=Delaware Basin; EPB=Elk Point Basin; HBB=Hudson Bay Basin; IB=Illinois Basin; IwB=Iowa Basin; MB=Michigan Basin; ME=Mississippi Embayment; MRB=Moose River Basin; OB=Oklahoma Basin; OU=Ozarka Uplift; PB=Pilot basin; PRA=Peace River Arch; TCA=Trans-Continental Arch; WAR=West Alberta Ridge; WB=Williston Basin; ZDU=Zuni-Defiance Uplift (modified from Algeo et al., 2007).

2.3. Structure

Precambrian basement of the Williston Basin is made up of the Archean Superior craton, Archean Wyoming craton, and the Trans-Hudson orogenic belt along which the two cratons were sutured (Figure 9; Anna et al., 2010). Collision between the Archean Superior and Wyoming cratons created a north-south trending strike-slip fault and shear belt, and north-east trending fault and structural zones (Anna et al., 2010). The fault and structural zones are currently known as the Transcontinental Arch, Brockton-Froid fault zone, Great Falls tectonic zone, Poplar fault, and Hinsdale fault. Reactivation of these structures influenced later structures, which are the

Nesson, Cedar Creek, Little Knife, and Billings anticlines, as well as the Bismark-Williston lineament and Goose Lake trend (Figure 10; Anna et al., 2010).

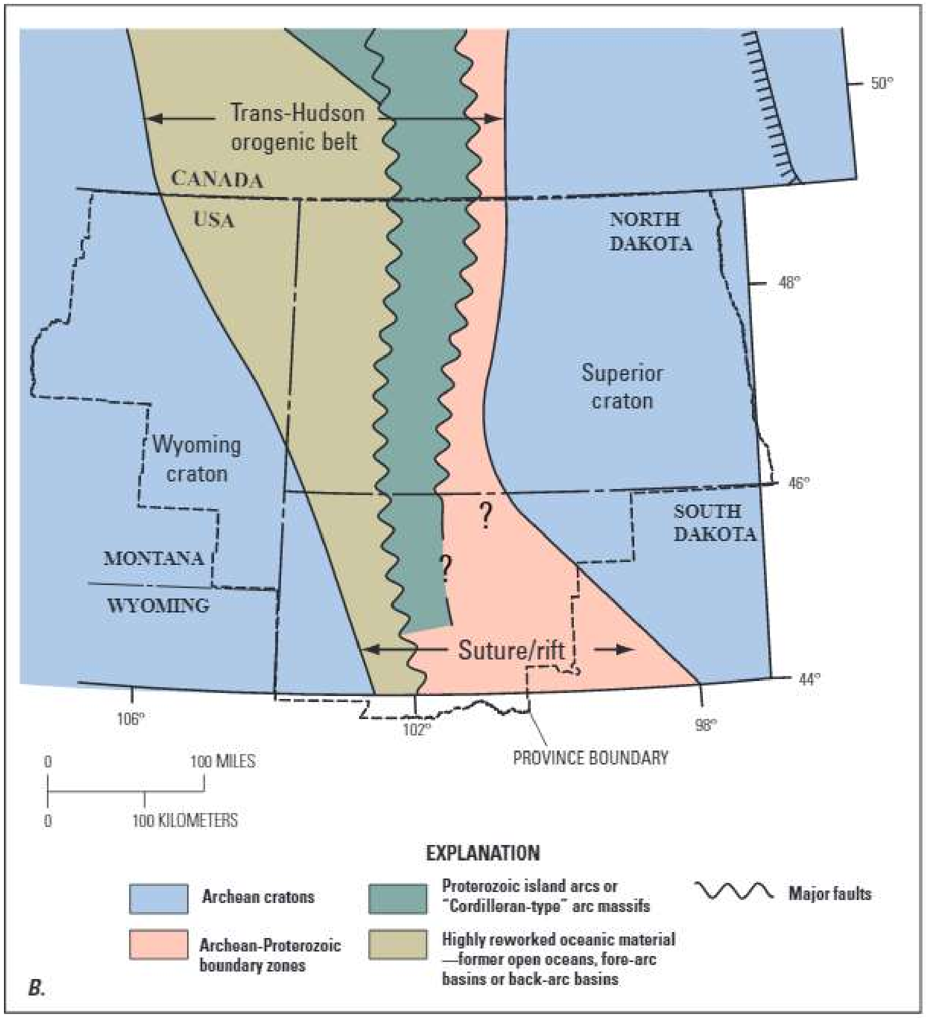


Figure 9. Precambrian tectonic configuration of the Trans-Hudson orogenic belt (from Anna et al., 2010).

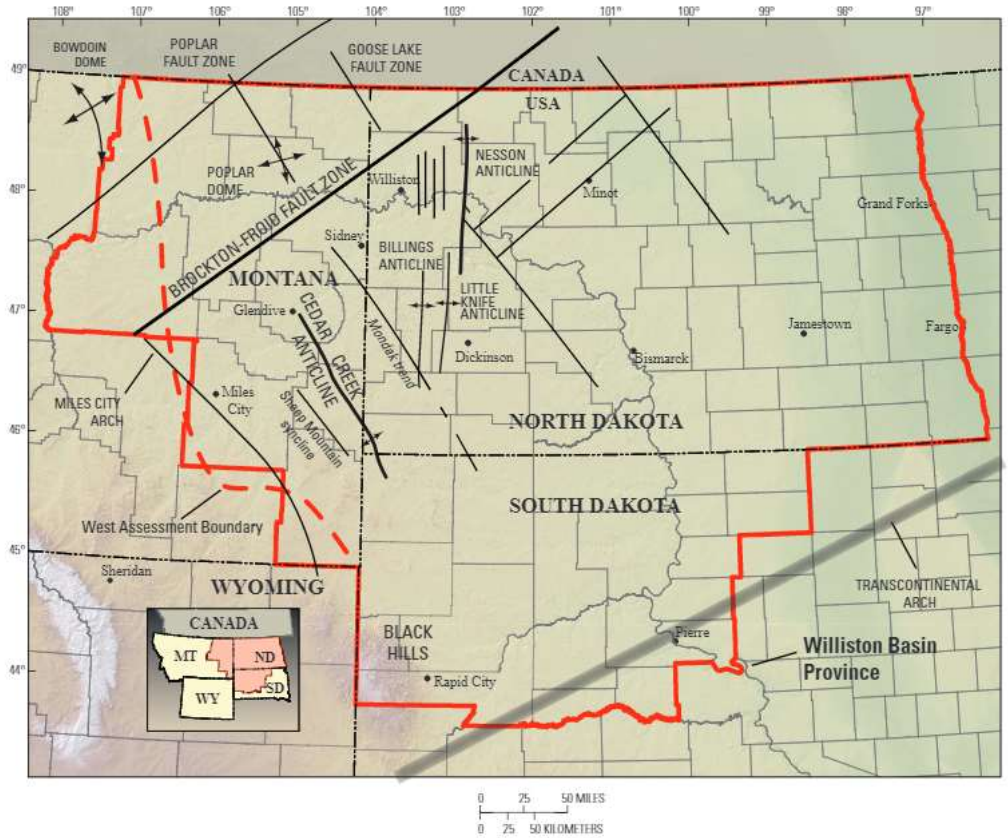


Figure 10. Features of the Williston Basin Province in the United States. Solid red line is the boundary of the Williston Basin Province. Dashed red line shows the western boundary for oil and gas assessment units. Unlabeled black lines are major lineaments or faults. Labeled black lines are other major structural features (from Anna et al., 2010).

The Williston Basin initially formed during the Late Ordovician as a depressed block between the Brockton-Froid-Fromberg and Colorado-Wyoming shear systems (Gerhard and Anderson, 1988). Tectonically active structures near and within the Late Devonian-Early Mississippian basin include the Central Montana Uplift, Cedar Creek Anticline, Nesson Anticline, Poplar Dome, Bowdoin Dome, Transcontinental Arch (Sandberg, 1961; Smith and Bustin, 1997; Lindsay et al., 1988), and the Prophet Trough, Sweetgrass Arch, and Peace River Embayment in Canada (Figure 11; Richards, 1989).

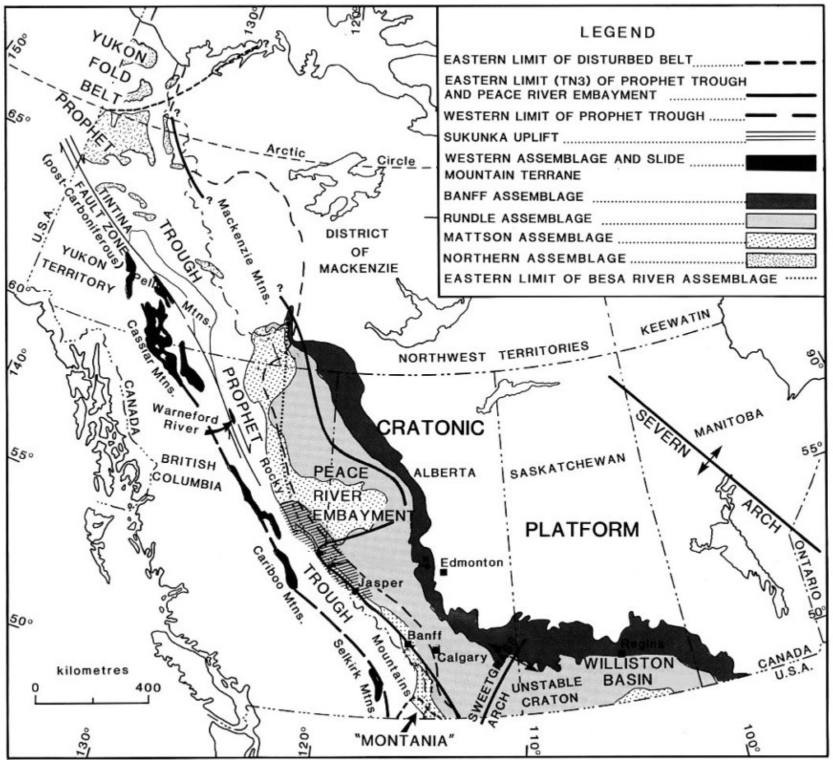


Figure 11. Tectonic elements of uppermost Devonian and Lower Carboniferous (upper Kaskaskia sequence) and lithofacies assemblages in the Western Canada Sedimentary Basin (modified from Richards, 1989).

Regional uplift along the Transcontinental Arch during Early Devonian tilted Williston Basin northward and established marine communication through what is now Alberta to the ocean (Lindsay et al., 1988; Anna et al., 2010) creating what is called the Elk Point Basin. The Bakken Formation was deposited in the Elk Point Basin (Figure 12b). The North Dakota and Elbow sub-basins were depocenters of the Elk Point Basin, and were separated by the Swift Current and Regina-Melville platforms (Figure 13 and Figure 14; Smith and Bustin, 1997). The basin cycled through restricted marine conditions and normal circulation conditions coupled with sea-level changes throughout the Late Devonian-Early Mississippian. Reversal of Williston Basin's northward tilt in the Middle Mississippian terminated the Elk Point Basin and established connection to the Cordilleran sea through a narrow marine connection called the Montana Trough (Figure 12c; Lindsay et al., 1988; Anna et al., 2010).

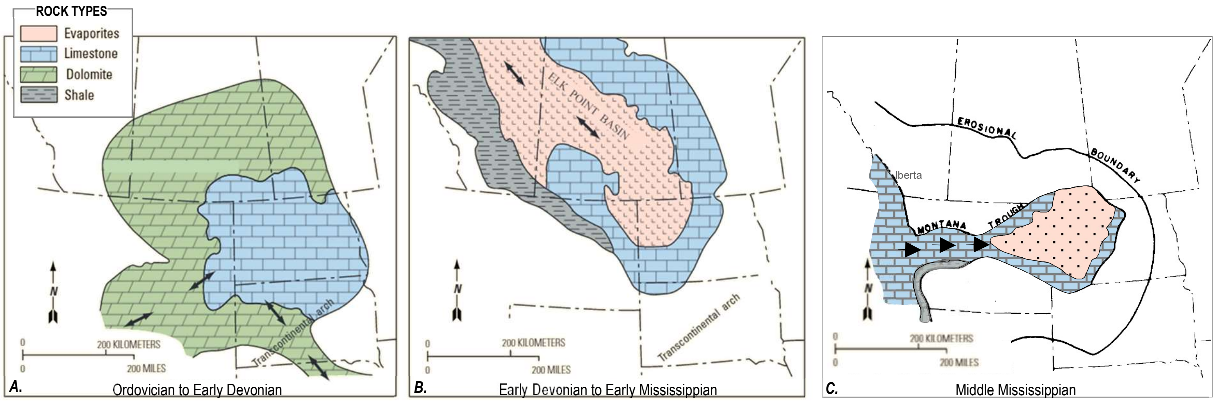


Figure 12. Williston Basin depositional patterns from Ordovician to Middle Mississippian. (A) Ordovician to Early Devonian, showing southwest and southeast seaway connections. (B) Early Devonian to Early Mississippian, showing a northwest seaway connection through the Elk Point Basin. (C) Middle Mississippian, showing a west seaway connection through the Montana Trough. Arrows indicate direction of water movement. Double ended arrows indicate water interchange and single ended arrows indicate one primary flow direction (modified from Lindsay et al., 1988 and Anna et al., 2010).

The Williston Basin’s Middle Devonian Prairie Formation, also referred to as the Prairie Evaporite Formation (Sandberg and Hammond, 1958), contains several beds of evaporite. Dissolution of these evaporites over time resulted in collapse features as well as local “thicks” in overlying formations (LeFever and LeFever, 2005). The Prairie is the sixth formation underlying the Bakken Formation (LeFever and LeFever, 2005).

Middle Bakken thickness in the northern portion of the international Williston Basin is shown in Figure 14. There is regional and local thickening and thinning within the Williston Basin. Regional thickness changes were influenced by the Swift Current and Regina-Melville platforms and Elbow and North Dakota sub-basins. Localized thick trends were partially influenced by dissolution of underlying Prairie Formation evaporite.

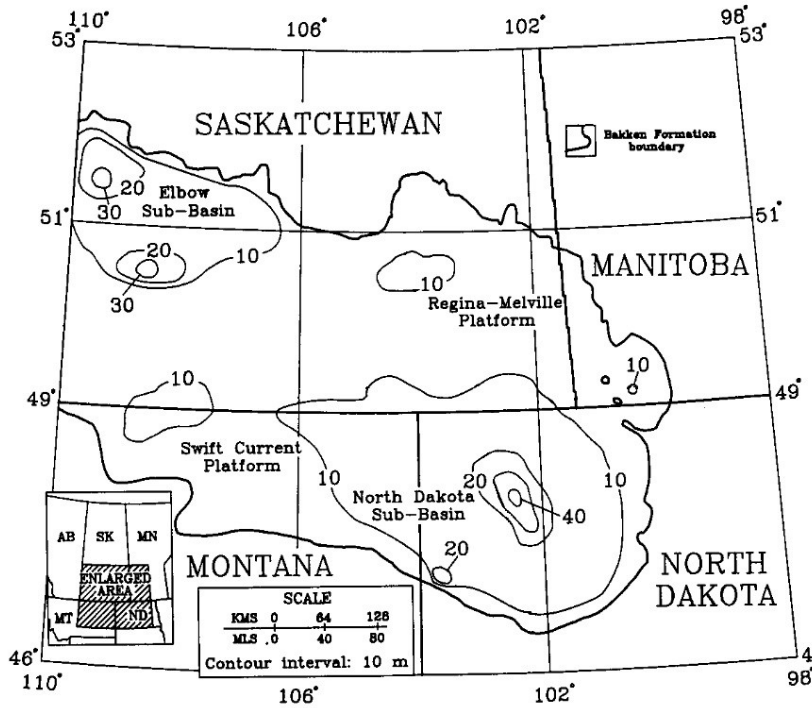


Figure 13. Isopach of the Bakken Formation showing locations of sub-basins and platforms (modified from Smith and Bustin, 1997).

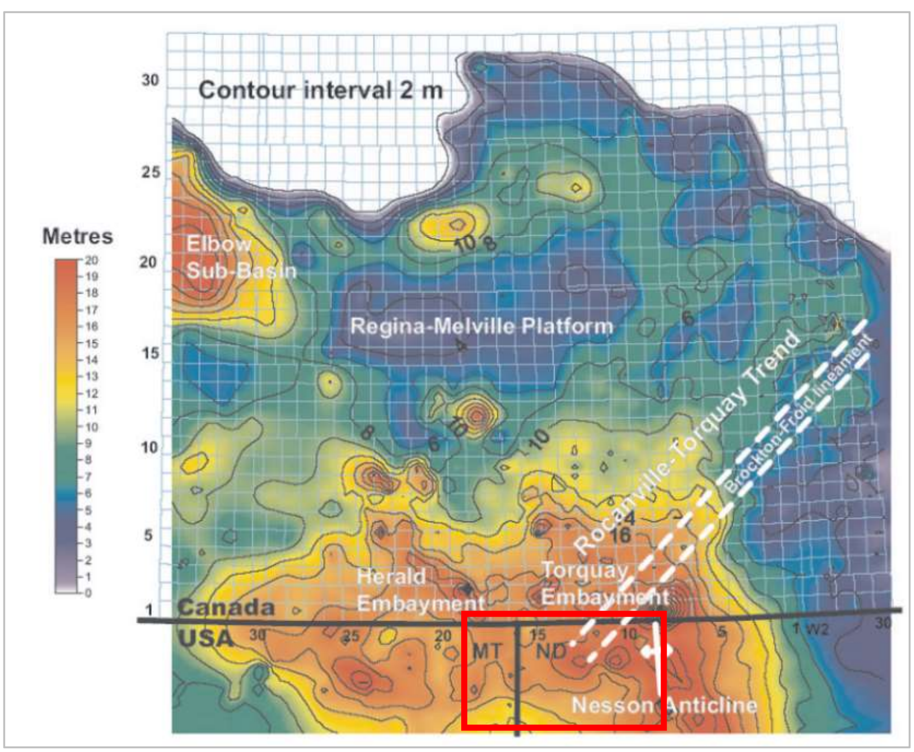


Figure 14. Middle Bakken thickness in the northern US and southern Saskatchewan (modified from Kreis and Costa, 2005). Approximate study area of this thesis is outlined in red.

2.4. Sedimentology

Sedimentation in the Williston Basin occurred from the Cambrian to Tertiary and is represented by over 16,000 ft (4,878 m) of sedimentary rock (Pitman et al., 2001). The basin was one of many basins in the Devonian-Carboniferous North American Seaway (Figure 8). Lack of vertical and horizontal mixing of deeper waters within these basins led to anoxic bottom waters and deposition of shales across the continent (Ettensohn and Barron, 1981; Brand, 1992; Smith and Bustin, 1998; Algeo et al., 2007). In North Dakota these shales are represented by the upper and lower shale members of the Bakken Formation.

The lower shale member of the Bakken was deposited during a transgression and accumulated in basin centers before spreading toward basin margins as relative sea-level rose (Smith and Bustin, 1997). Lower and middle layers of the middle member were deposited after a relative sea-level drop, where a forced regression caused accumulation of entrained sediments entering the basin to by-pass marginal areas of the basin and accumulate in the interior. The uppermost ~20% of the middle Bakken was deposited during a sea-level rise and onlapped onto early middle Bakken sediments. The upper shale member of the Bakken was deposited in another significant transgression as relative sea-level rose (Smith and Bustin, 1997).

Middle Bakken clastic sediments were likely sourced from north, east, and south of the Williston Basin from the Franklinian clastic wedge, Ellesmerian Orogeny, Canadian Shield, Grenville province, and Mazatzal-Yavapai provinces (Figure 15; Mohamed and Henderson, 2015).

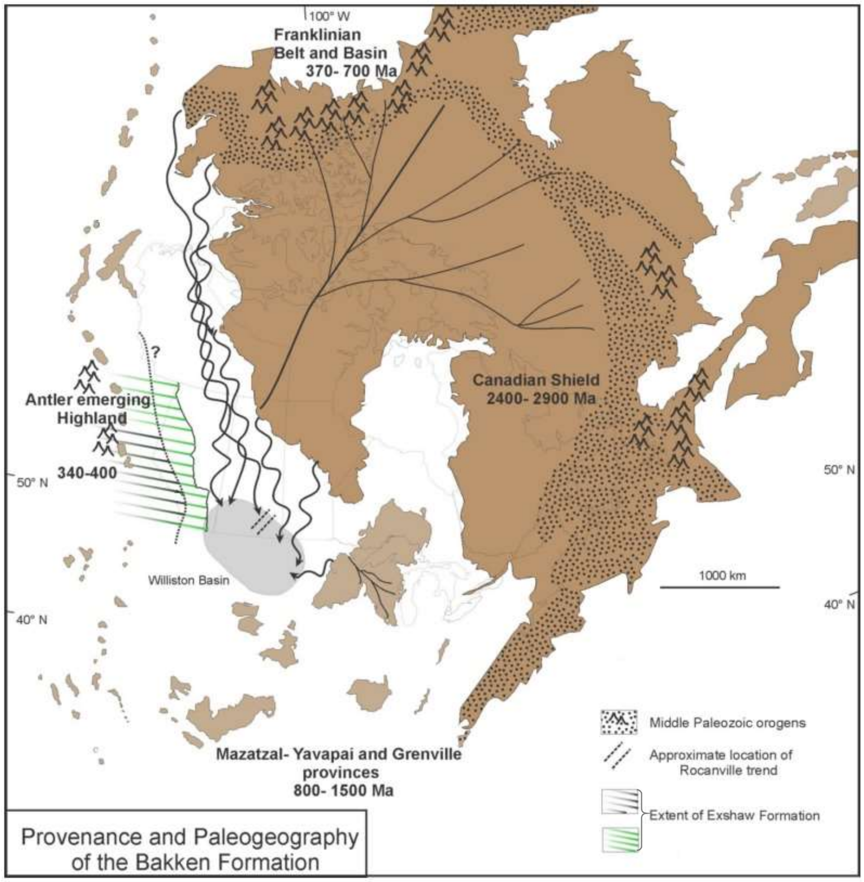


Figure 15. Provenance interpretation of the Bakken Formation and paleogeography of North America during Early Mississippian. Detrital zircon suggests sediment sources from the Franklinian belt, Canadian Shield, and Grenville and Yavapai-Mazatzal provinces (modified from Mohamed, 2015).

2.5. Stratigraphy

The Bakken Formation overlies the Three Forks Formation and is overlain by the Lodgepole Formation (Figure 16). The Three Forks Formation generally conformably overlies the Birdbear Formation and is unconformably overlain by the Bakken Formation (Sandberg, 1961). The formation was originally named the "Three Forks shale", which described beds between the Jefferson Limestone and Madison Limestone of Peale (1893), near the junction of the three forks of the Missouri River. The Three Forks Formation ranges from 0 to ~240 ft in Montana and North Dakota, and is thickest in the Williston Basin east and south of the Nesson

Anticline (Sandberg, 1961). The formation is composed of dolomitic siltstone and shale, with the lower half commonly more anhydritic (Sandberg, 1961).

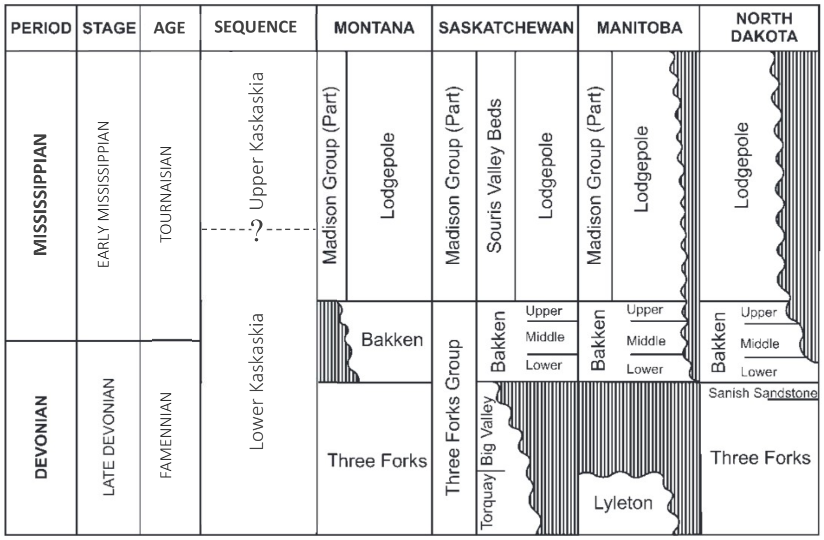


Figure 16. Stratigraphic chart for the Late Devonian-Early Mississippian Williston Basin of Montana, Saskatchewan, Manitoba, and North Dakota (modified from Anna et al., 2010 and Angulo and Buatois, 2012).

The Bakken Formation was named for its type well, the H.O. Bakken No. 1 (Nordquist, 1953). The formation is Late Devonian (latest Famennian) to Early Mississippian (earliest Tournaisian), and has three informal members: the upper shale, the middle dolomite/siltstone, and the lower shale (Smith and Bustin, 1998).

The Lodgepole Formation conformably overlies the Bakken Formation (Nordquist, 1953) and is conformably and transitionally overlain by the Mission Canyon Formation (Sando, 1960). The formation was formally termed by Collier and Cathcart (1922) as part of the Madison Group and was named for Lodgepole Canyon in the Little Rocky Mountain in the Montana portion of the Williston Basin. The formation is composed of cherty, argillaceous limestone with thin shale interbeds (Collier and Cathcart, 1922).

3. Methods

A petrographic microscope was used to conduct point counting to determine the variability of grain lithology and size, as well as sediment source, distribution, and deposition. A scanning electron microscope was used to determine types of cements, relative relationships of cements, and lateral extent of cements. Type logs were created and used to correlate wells across the study area to determine facies continuity and to determine thickness changes of members and units within the Bakken Formation. Prairie Formation thickness was mapped to determine if dissolution of the formation’s evaporite impacted Bakken Formation sedimentation.

3.1. Optical Petrography

Point counting is a quantitative method for determining mineralogy of a thin section. Grain provenance of the Bakken Formation’s middle member was determined by point counting 18 thin sections in the Torgeson 2-15HS and 14 thin sections in the Tomlinson 3-1HN wells using the Glagolev-Chayes method (Galehouse, 1971). In the Glagolev-Chayes method of point counting, a thin section is sampled using a grid of points. A point counting stage moves the thin section left-to-right and top-to-bottom in equally spaced segments to create a grid of points. At each point, information about the grain under the cross-hairs of the microscope is recorded. A typical setup of equipment for point counting is shown in Figure 17.

Figure 17. Typical setup of a petrographic microscope and stage for point counting.

3.1.1. Preparation

Thin sections for the Torgeson 2-15HS and Tomlinson 3-1HN wells were provided by SM Energy, and had been set in a pink epoxy and stained for calcite with alizarin red stain prior to this study. The alizarin red stain was only applied to half of each thin section. Cover slips and a temporary fluid of glycerol were placed on the thin sections (Figure 18) to make grain contacts more pronounced. The temporary fluid was changed from glycerol to deionized water after observing alizarin red stain fade and partially dissolve in glycerol.

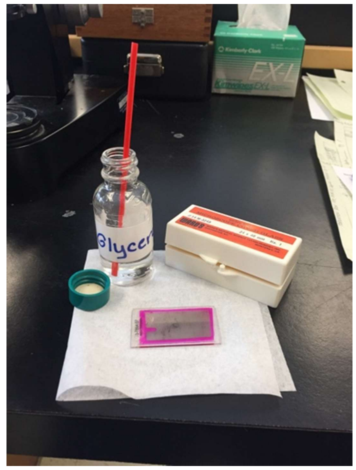


Figure 18. Point count thin section preparation with glycerol and cover slip.

3.1.2. Point Counting

One point count was completed for mineralogy and a second point count was completed for grain size and grain angularity for each of the 32 thin section slides. Grains as small as clay were included in the mineralogy count. Grains as small as very fine silt were included in the size and angularity count. A minimum of 300 points per thin section were counted for mineralogy. A minimum of 100 points per thin section were counted for grain size/angularity. After methods of Van der Plas and Tobi (1965), counting 300 points per thin section yields ~5% error and counting 100 points per thin section yields ~7% error.

Following the methods of Graham et al. (1976), mineralogy was separated into categories of grain, void space, matrix, or cement, and then classified as either monocrystalline quartz, polycrystalline quartz, potassium feldspar, plagioclase feldspar, calcite, dolomite, microcrystalline calcite/dolomite, clay, opaques, fluorapatite+anhydrite, or “other”. The matrix material category includes clay and micrite. Micrite includes microcrystalline dolomite and microcrystalline calcite. The amount of cement includes calcite and dolomite cement, but not microcrystalline dolomite or microcrystalline calcite. The first few thin sections that were point counted did not separate micrite from dolomite and calcite cement. Most of these thin sections were re-counted to include micrite, but the Torgeson 2-15HS thin sections at 7896 ft and 7912 ft never got re-counted to include micrite. Differentiating void space from calcite cement was difficult as both the thin section epoxy and calcite stain of alizarin red appeared pink in color. In some thin sections the calcite alizarin red stain was partially faded, which made it difficult to discern if minerals were calcite or dolomite.

Grain size was measured with a millimeter ruler and classified as either very coarse, coarse, medium, fine, very fine, or silt/clay sized. There are multiple methods to obtain grain sizes from thin sections (Kellerhals et al., 1975) and none of them is preferred singularly above the rest. Grain sizes from thin sections generally underestimates grain size because most grains are not cut through the middle of the grain (Johnson, 1994). To get a more accurate grain size in the point count, grains were measured along their longest axis.

Angularity was visually determined with a roundness and sphericity comparison chart from Pettijohn (1975) and was classified as either well rounded, rounded, sub-rounded, sub-angular, angular, or very angular.

3.2. Diagenesis

An Oxford energy dispersive spectroscopy system (EDS) and back scatter electron images on a Tescan Vega III scanning electron microscope (SEM) at the University of Montana were used to determine mineralogy in different stages of diagenesis in the Torgeson 2-15HS and Tomlinson 3-1HN wells. Elemental compositions of dolomite cement throughout the samples were taken and compared to determine if diagenesis was localized at each well or on a larger scale. Torgeson 2-15HS slide 12 and Tomlinson 3-1HN slides 5, 7, and 11 were selected for the SEM due to their larger grain size and sandstone facies. Four dolomite compositions were taken in the Torgeson 2-15HS slide 12. In the Tomlinson 3-1HN well, two dolomite compositions were taken in slide 5, two were taken in slide 7, and six were taken in slide 11.

3.3. Subsurface Mapping

Compensated Neutron Density (CND) or Dual Laterolog (DLL) well logs for 606 wells in the study area were loaded into IHS Petra® (Figure 19). Vertical well logs were used for correlations to forego the deviation correction needed for horizontal wells.

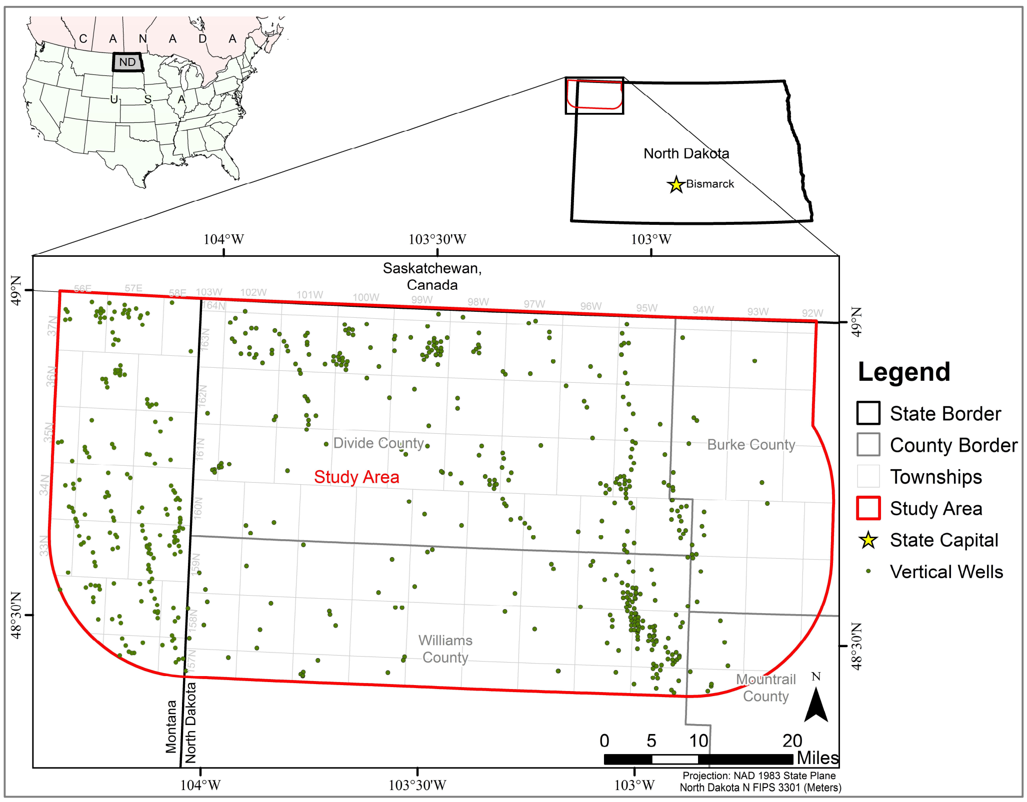


Figure 19. Location of the 606 vertical wells correlated for this study.

Shapefiles comprising well information were downloaded from the North Dakota Industrial Commission (NDIC) Department of Minerals Resources Oil and Gas Division and Montana Board of Oil and Gas (MBOG) ArcGIS servers before being filtered to show only vertical wells penetrating the Bakken Formation and located within Divide County, ND and in a 15 mile radius around Divide County in the United States. Information from these wells was then imported into Petra. North Dakota well logs were downloaded individually from the NDIC website and renamed with their API number for batch import into Petra. Montana well logs were imported en masse into Petra using LogSleuth/MJ Systems. Nearly all North Dakota well logs were raster logs and were imported into Petra as uncalibrated TIF files. The uncalibrated raster logs were calibrated using the Petra Raster Calibration module by marking the left and right sides of the well logs, the top and bottom of the log header, the top and bottom of the upper and lower log scales, and the log depths.

Reported tops for the Prairie Formation and underlying Winnipegosis Formation in Montana, North Dakota, and Saskatchewan wells were downloaded from the MBOG, NDIC, and AccuMap, respectively before import into Petra. An isopach map of the Prairie Formation was created for this study and used to check local thicks in the Bakken Formation.

Core descriptions for the Torgeson 2-15HS and Tomlinson 3-1HN wells (Hofmann et al., 2014) were tied-in to their respective well logs to identify tops and to use as type logs for well correlations. The tie-ins required core depths to be adjusted to log curve depths. The Torgeson 2-15HS well did not require any core to log shift. The Tomlinson 3-1HN well required an eight foot core to log shift.

All 606 vertical well logs in the study area were correlated with the Torgeson 2-15HS and Tomlinson 3-1HN type logs in Petra. North Dakota well logs were correlated in groups working from the northwest corner to the northeast corner, then from the southeast corner to the southwest corner of the study area. After logs in North Dakota were correlated, well logs in Montana were correlated from the south to north. All tops were correlated throughout all wells. If a top was non-existent in a log, then it was placed at the same depth as the next existent top.

The correlated tops in Petra were used to create cross-sections, structure maps, and isopach maps. Grids in Petra were created for each map before kriging to get contours for the structure and isopach maps.

After correlating well logs and making maps, five additional core descriptions from SM Energy were made available to this study. The additional core descriptions were tied-in to their respective well logs and compared with prior correlations to check the quality of correlations. The additional descriptions were also used to discern non-correlative tops. Sections containing multiple non-correlative tops were then lumped together. The five additional wells with core descriptions available are termed “test wells” in this study.

4. Results

Hofmann et al. (2014) lithofacies were modified for this study and renamed as lithofacies A through H (Figure 20). The lithofacies distribution in the Tomlinson 3-1HN core is shown in Figure 21.

This Study		
Lithofacies		
	A	Bioclastic Muddy Siltstone
 	H	Bioturbated Interbedded Mudstone-Sandstone/Mudstone & Sandstone
	B	Bioturbated Siltstone
	C	Parallel Laminated Silty Sandstone
	D	Micro-Cross Laminated Siltstone & Silty Sandstone
	E	Ripple Cross-Laminated Sandstone
	G	Parallel Laminated Sandstone
	F	Bioturbated Sandstone

Figure 20. Lithofacies of the middle member of the Bakken Formation for this study. Lithofacies modified from Hofmann et al. (2014).

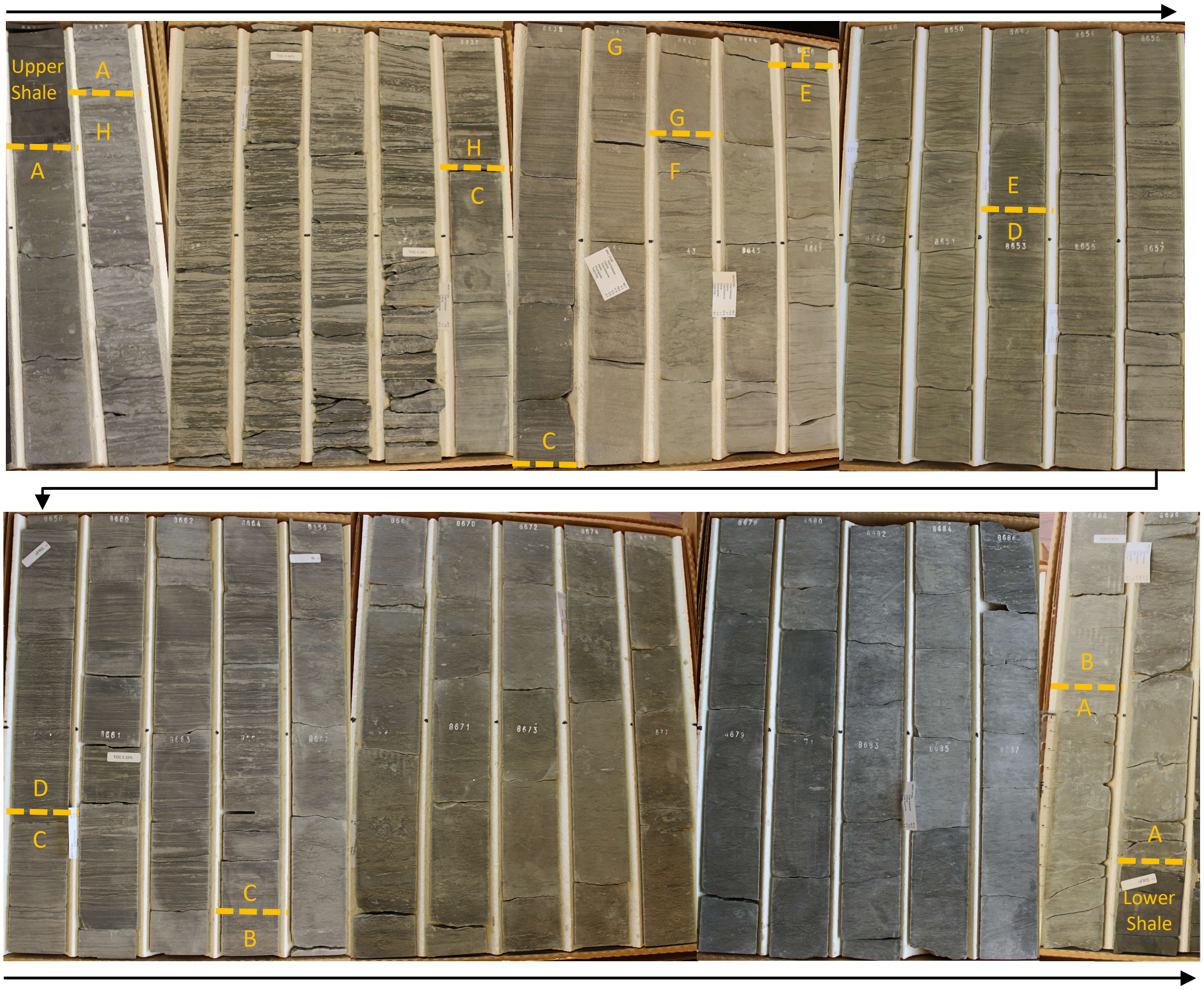


Figure 21. Tomlinson 3-1HN core boxes with middle Bakken lithofacies described in Figure 20. Black arrows indicate order of core boxes from upper shale to lower shale. Lithofacies breakdown modified from Hofmann et al. (2014).

4.1. Optical Petrography

Thin section slides showing each facies A-H are in Figure 22. An example of minerals in thin section is in Figure 23. Enlarged images of thin sections for each facies A-H are in Figure 24. Tables containing point count data for grain mineralogy are in Appendix A. Tables containing point count data for grain size and angularity are in Appendix B. There were some fossils throughout the thin sections, but their diversity was not recorded for this study.

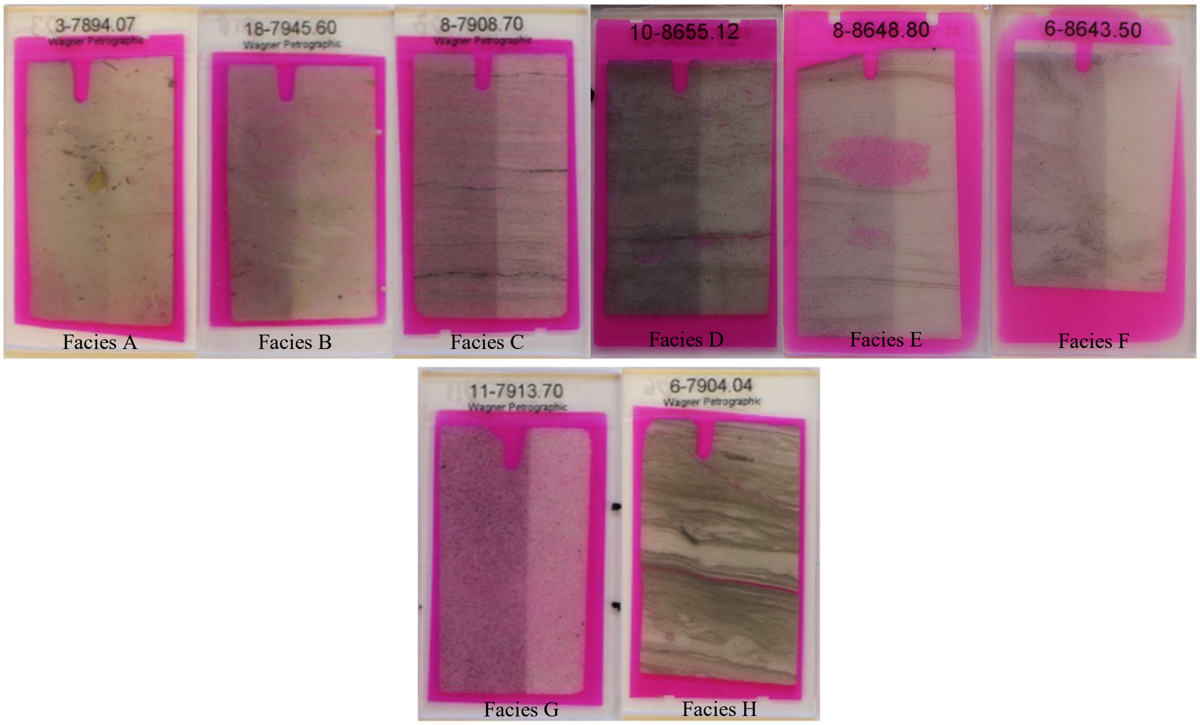


Figure 22. Thin sections showing each facies A-H. Thin section slides for facies A, B, C, G, and H are from the Torgeson 2-15HS well. Thin section slides for facies D, E, and F are from the Tomlinson 3-1HN well.

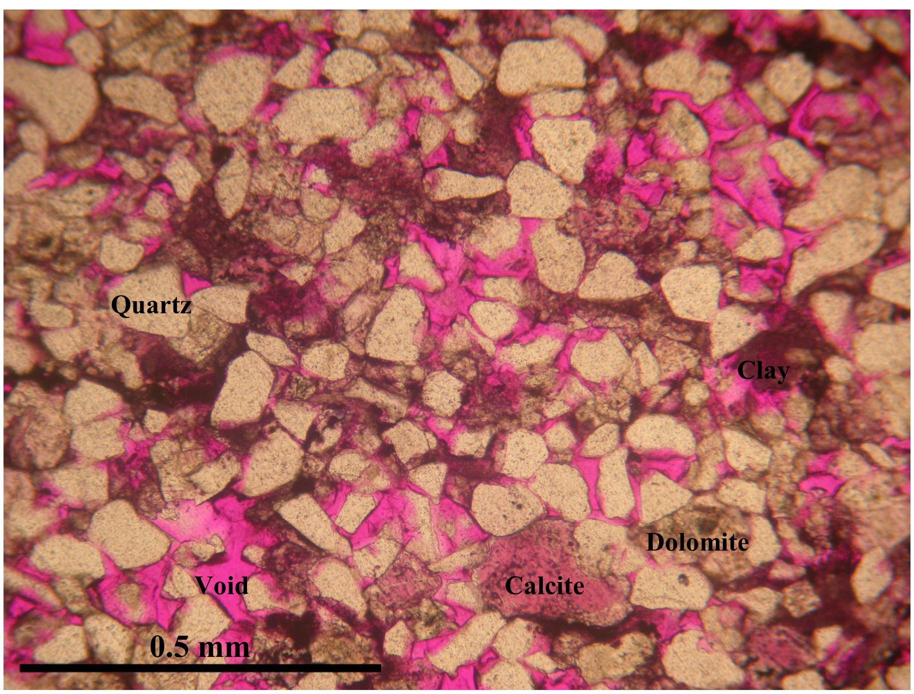


Figure 23. Example of minerals in thin section. Torgeson 2-15HS facies G at 7931.70 ft core depth. Image taken with plane polarized light.

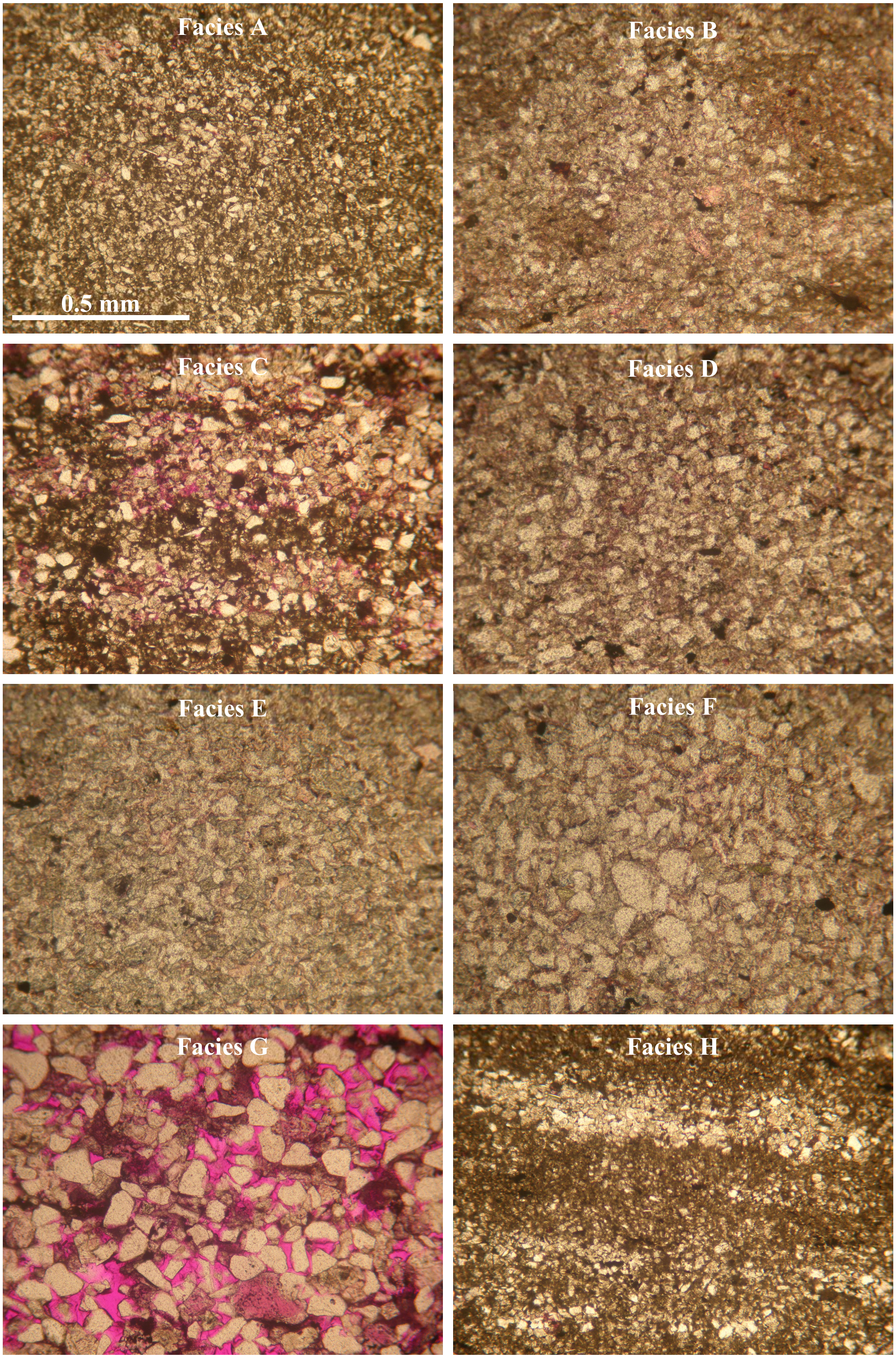


Figure 24. Enlarged thin section images showing each facies A-H. All images have the same field of view. Images taken with plane polarized light.

4.1.1. Mineralogy

Point count results for middle member mineralogy of the Bakken Formation in the Torgeson 2-15HS well are in Figure 25. Torgeson 2-15HS has a general trend of increasing quartz from 7953.5 ft to 7912 ft, and then decreasing quartz from 7912 ft to 7894.07 ft. The amount of calcite cement varies throughout the thin sections. Thin sections below facies G, from section 7921.78 ft to7945.6 ft, have nearly no calcite cement. Thin sections near the lower shale member show an increase of calcite cement from near zero percent to 23% and 36% in sections at 7950 ft and 7953.5 ft respectively. The amount of dolomite varies throughout the thin sections from 14% to 56%. The amount of micrite decreases from the uppermost and lowermost thin sections to the middle thin sections in facies G. The thin section at 7917.25 ft did not have any micrite. Thin sections at 7896 ft and 7912 ft never got recounted to record micrite. For these two sections, micrite was counted as either calcite or dolomite cement. Clay content is the highest in facies G at 7917.25 ft and decreases upwards and downwards to 7906.3 ft and 7935.37 ft respectively before increasing to 11% then decreasing towards the uppermost and lowermost sections. There is a trend of increasing opaques from 7910 ft to 7894.07 ft. Facies G has the highest amount of quartz and lowest amount of cement, with quartz content decreasing towards the uppermost and lowermost thin sections. Facies A and B, in close proximity to the upper and lower shales, have the lowest amount of quartz and highest amount of cement. Most thin sections contain at least three times as much dolomite cement as calcite cement.

Point count results for the Tomlinson 3-1HN well are in Figure 26. Tomlinson 3-1HN has a general trend of increasing quartz from 8688.14 ft to 8641.15 ft, and then decreasing quartz from 8641.15 ft to 8630.15 ft. There is an overall trend of increasing calcite cement from the uppermost thin sections to the lowermost thin sections. The amount of dolomite cement varies throughout the thin sections and is the highest in facies B and E, and is the lowest

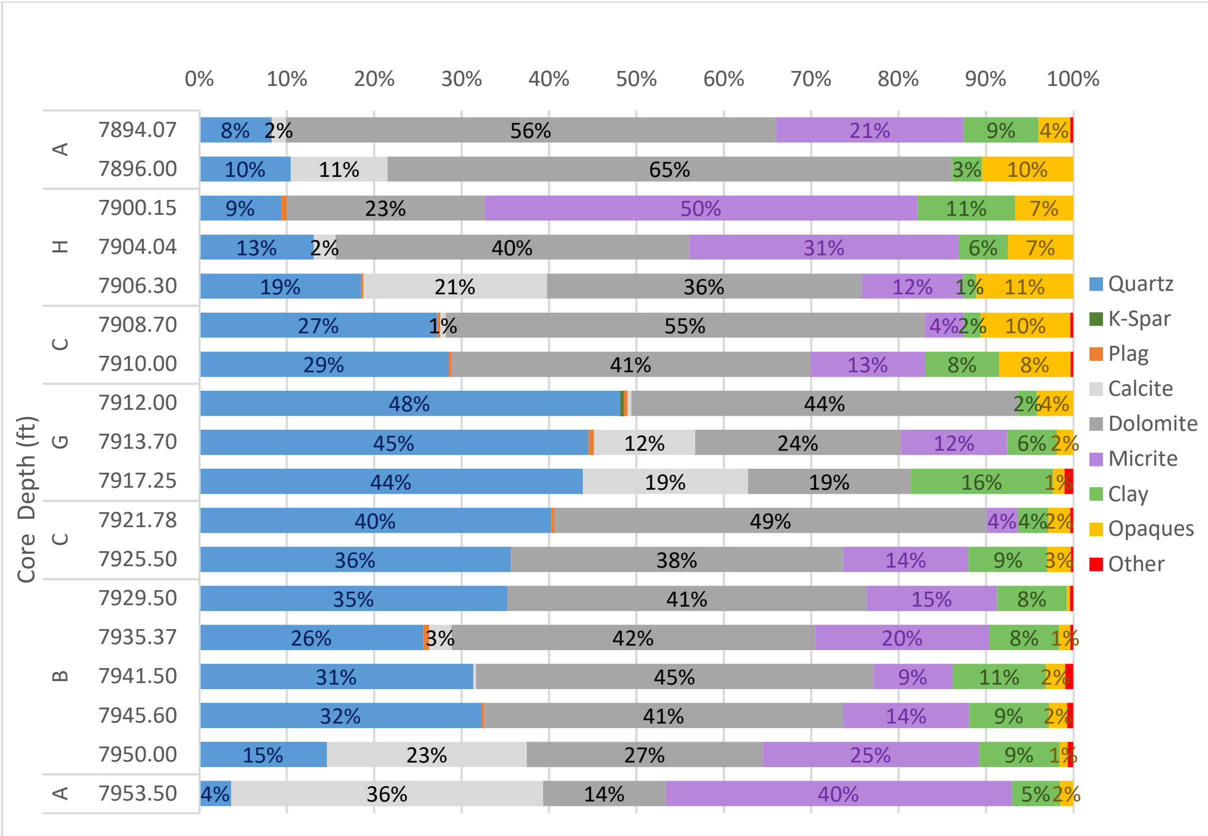


Figure 25. Torgeson 2-15HS middle Bakken mineralogy from point count data. Letters A through H are facies from Figure 20. Micrite is microcrystalline dolomite/calcite.

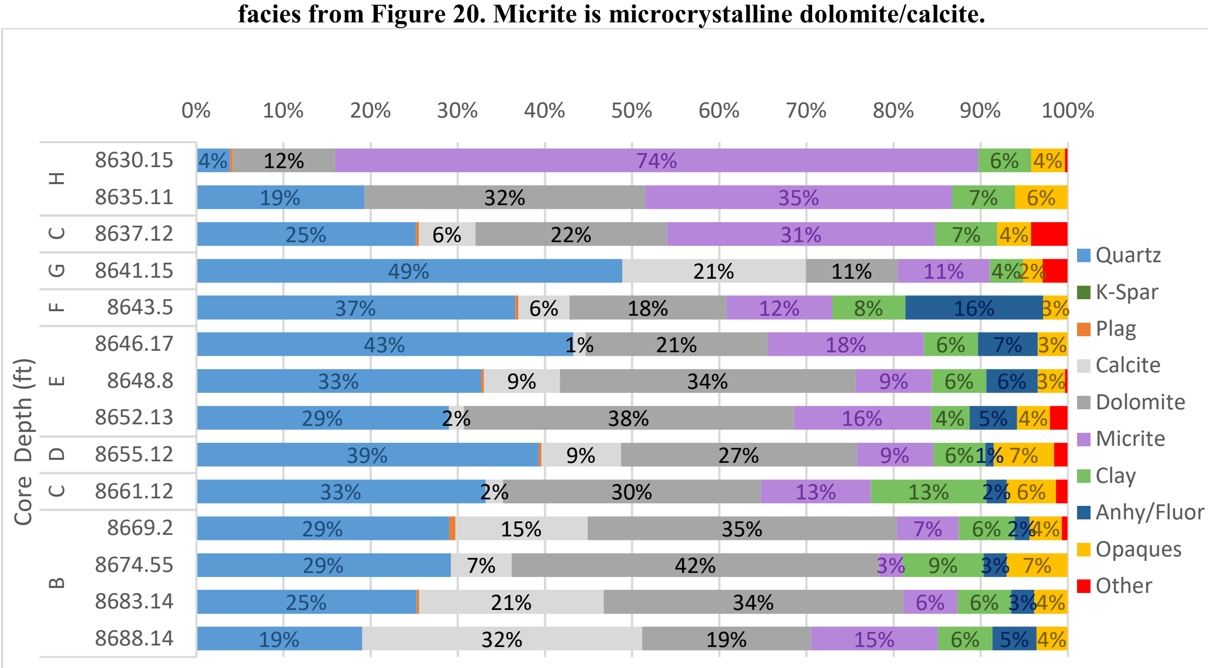


Figure 26. Tomlinson 3-1HN middle Bakken mineralogy from point count data. Letters A through H are facies. Anhy/Fluor stands for anhydrite and fluorapatite. Micrite is microcrystalline dolomite/calcite.

in facies G and H. Micrite content is highest at 8630.15 ft and generally decreases towards the lower shale member. Clay content in the thin sections is generally 4% to 9%, except at 8661.12 ft where clay content is 13%. Thin sections between 8643.5 ft and 8688.14 ft contain anhydrite/fluorapatite in a decreasing trend. The amount of opaques in thin sections varies from 3% to 7% with the lowest amount in facies F and G. Facies G has the highest amount of quartz content and lowest amount of cement/micrite, followed by facies E and D. Facies B and H have the lowest amount of quartz content and highest amount of cement/micrite. Most thin sections have at least twice as much dolomite cement as calcite cement.

Comparisons of porosity, clay, and cement for each facies in the Torgeson 2-15HS and Tomlinson 3-1HN wells are shown in Figure 27 and Figure 28. In both wells, the void space recorded in the point count overestimated the amount of porosity when compared to log porosity.

Torgeson 2-15HS has higher porosity values in facies C, G, and parts of B. The peak for void space at 7945.6 ft comes from thin section slide 18. This slide had a higher porous zone in the bottom 1.5 cm where the point count was completed, which caused the higher porosity and lower cement values. Clay content from the top of the middle member to facies G remains around 5% except for two peaks, one in facies H and one in facies G. Clay content increases to about 10% from the top of facies B to the bottom of the middle member. The amount of cement varies throughout the thin sections with peaks of low cement content in facies H, G, and parts of B.

The Tomlinson 3-1HN has higher porosity values in facies G and E. Thin sections from 8661.12 ft to the bottom of the middle member have higher baseline porosity than units above facies G. Clay content varied throughout the sections with peaks of lower clay content in facies F and E, and a peak of higher clay content in facies C unit MB 3. Cement content had an overall

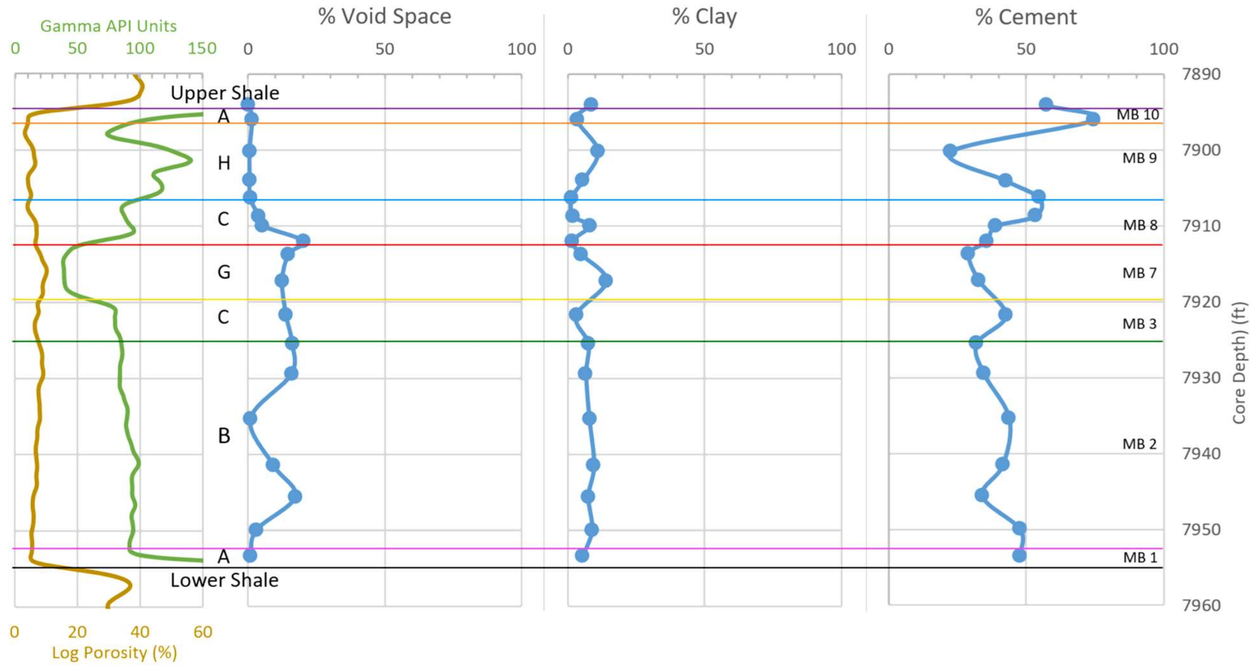


Figure 27. Torgeson 2-15HS middle Bakken comparison of percent voids, clay, and cement from point count data. Letters A though H are facies. Log depth matches core depth.

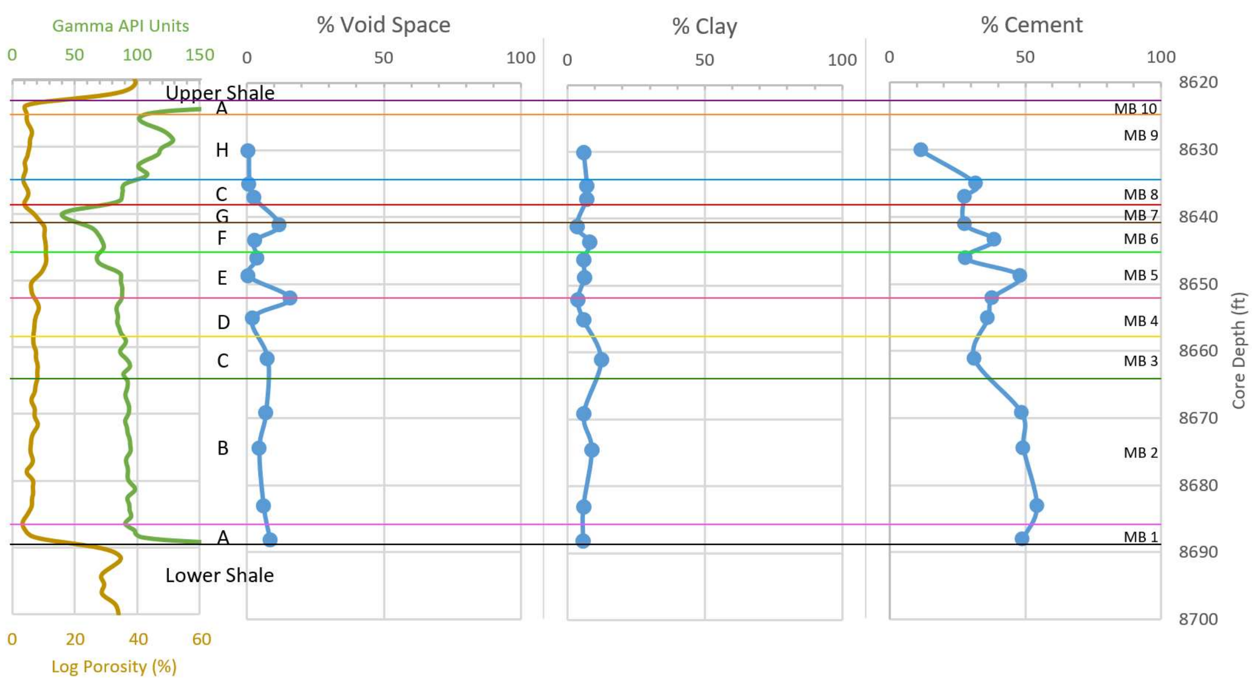


Figure 28. Tomlinson 3-1HN middle Bakken comparison of percent voids, clay, and cement from point count data. Letters A though H are facies. Log depth shifted to core depth.

trend of increasing from the top to the bottom of the middle member, with low cement peaks in facies C and G, and part of E.

A comparison of quartz content between the Torgeson 2-15HS and Tomlinson 3-1HN wells is shown in Figure 29. The percent of quartz increases from the lower shale member to facies G of the middle member and then decreases from facies G to the top of the middle member in both wells. The two wells have similar quartz contents from the top of the middle member to facies G, but the Torgeson 2-15HS has slightly more quartz than the Tomlinson 3-1HN in units beneath facies G.

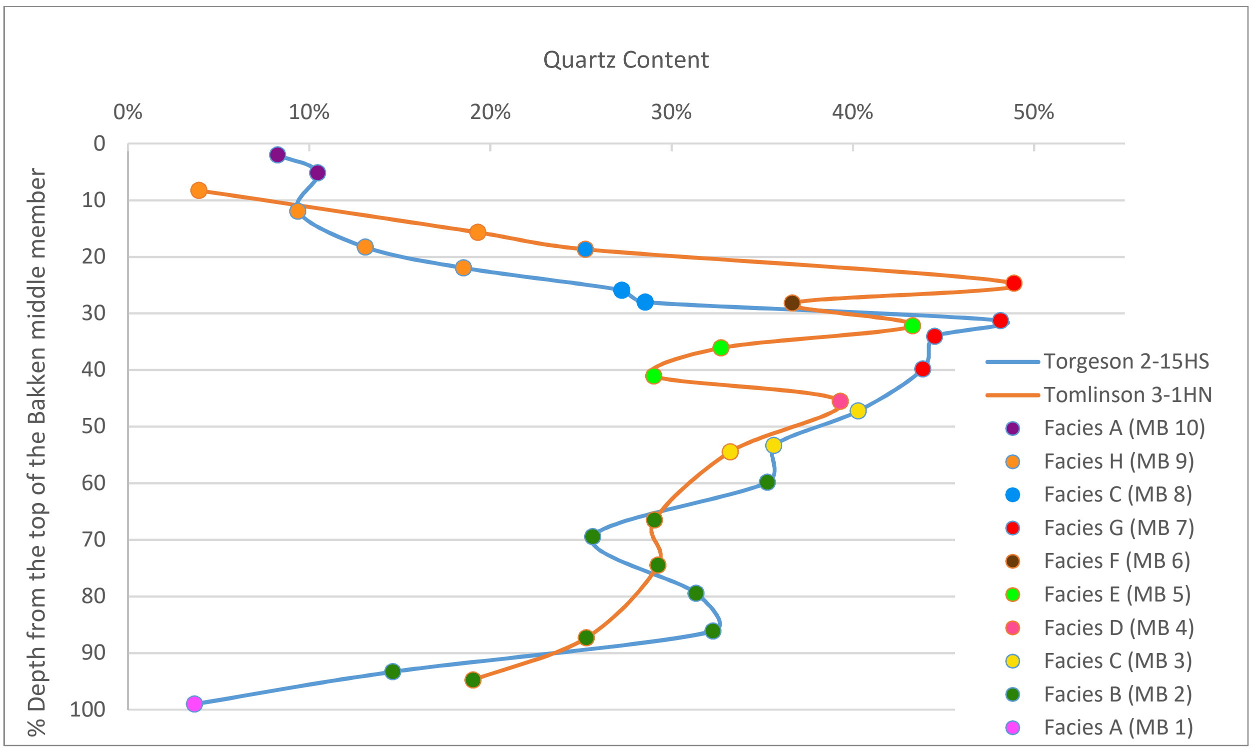


Figure 29. Comparison of quartz content in the Torgeson 2-15HS and Tomlinson 3-1HN wells. Letters A-H are facies. MB 1 to M10 are unit tops.

4.1.2. Grain Size

Point count results for middle Bakken grain size of the Torgeson 2-15HS and Tomlinson 3-1HN wells are in Figure 30 and Figure 31. Grain sizes ranged from silt/clay size to fine-grained size. Facies A (bioclastic muddy siltstone), B (bioturbated sandstone), and H (interbedded bioturbated mudstone-sandstone) have the highest amount of fine material with over 80% silt/clay sized grains. These facies have no fine-grained clasts. Facies C (parallel laminated siltstone), D (micro cross-laminated siltstone and silty sandstone) and E (ripple cross-laminated sandstone) have over 60% silt/clay sized grains and zero to 3% fine-grained clasts. Facies G (parallel laminated sandstone) and facies F (bioturbated sandstone) are the coarsest-grained out of all the facies, with most sections being about 30% fine-grained, 50% very fine-grained, and 20% silt/clay sized.

The coarsest grain sizes observed were fine and very fine-grained sand. A comparison in amount of fine and very fine-grained clasts between the Torgeson 2-15HS and Tomlinson 3-1HN wells is shown in Figure 32. The percent of coarsest-grained clasts shows an overall coarsening (shallowing) upwards trend from the lower shale member to facies G of the middle member and then an overall fining (deepening) upwards trend from facies G to the top of the middle member in both wells. The Tomlinson 3-1HN well has a small fining upwards sequence in facies E that the Torgeson 2-15HS does not have. The Torgeson 2-15HS has more fine and very fine-grained clasts from the top of the middle member to facies C (MB 3) and less fine and very fine-grained clasts below MB 3 than the Tomlinson 3-1HN.

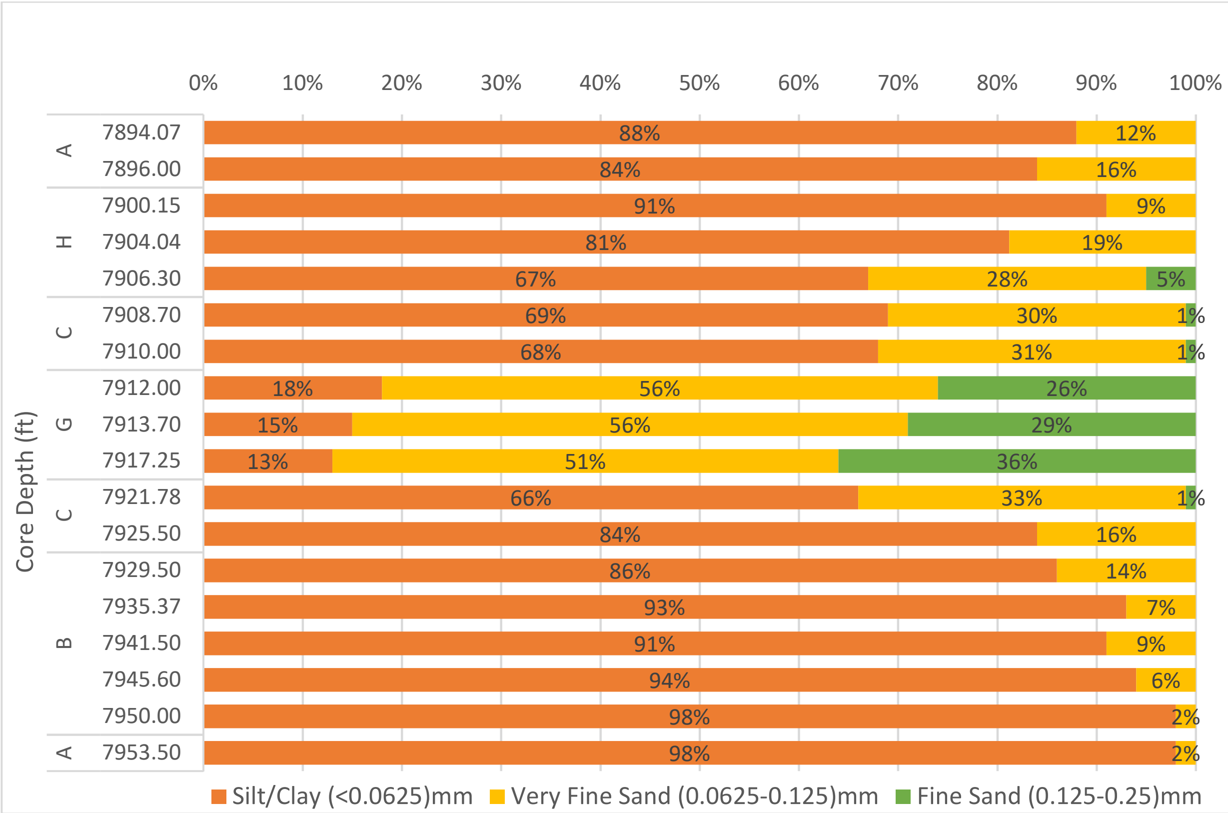


Figure 30. Torgeson 2-15HS middle Bakken grain size from point count data. Letters A through H are facies.

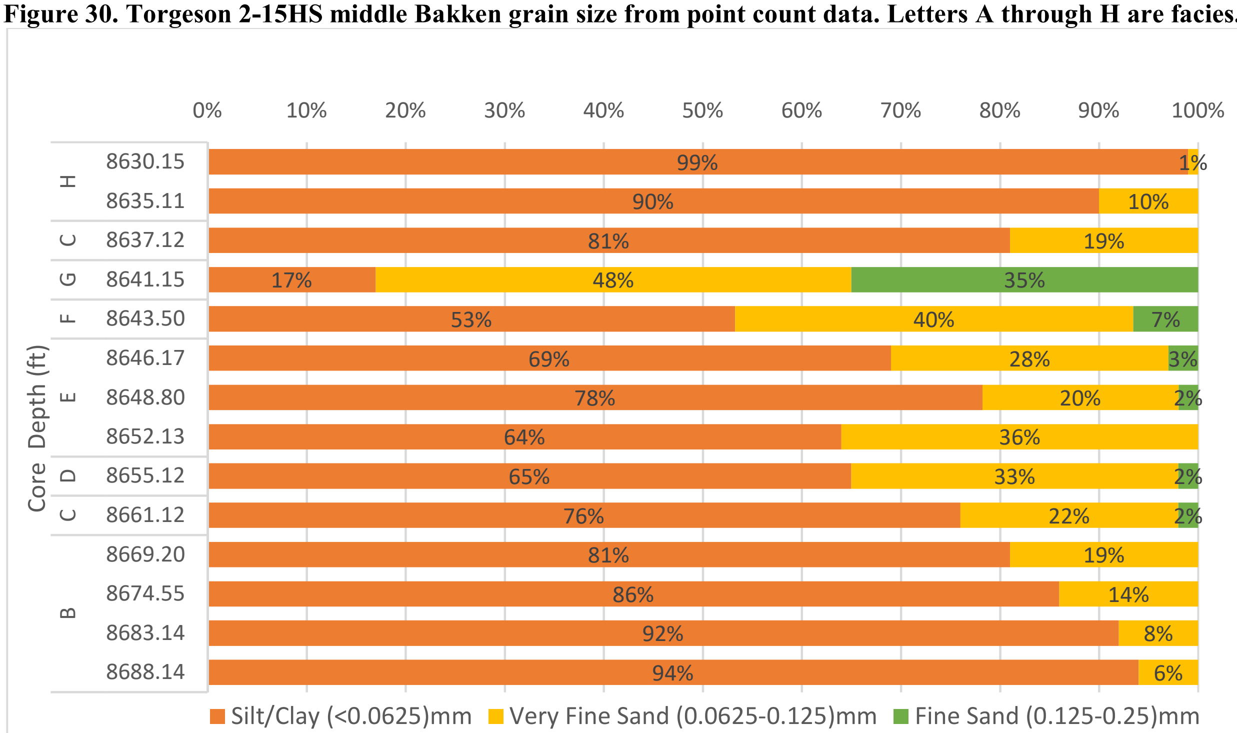


Figure 31. Tomlinson 3-1HN middle Bakken grain size from point count data. Letters A through H are facies.

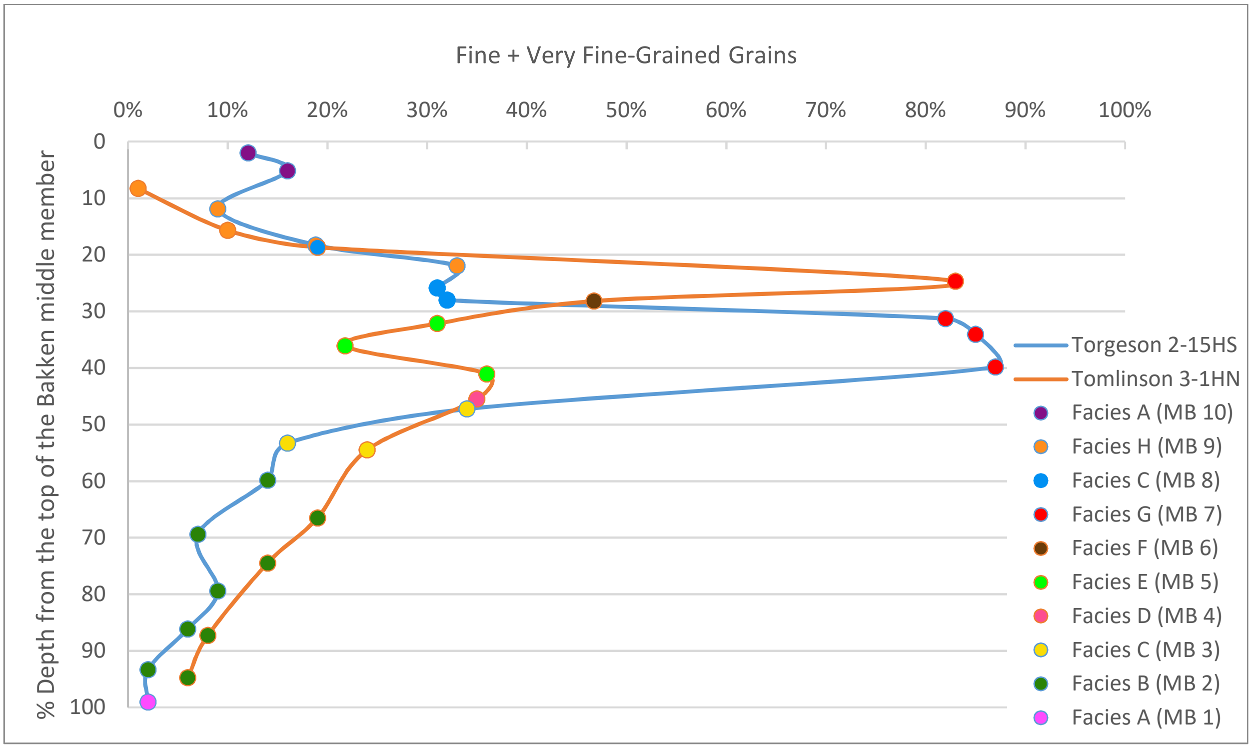


Figure 32. Comparison of fine and very-fine grained clasts in the Torgeson 2-15 and Tomlinson 3-1HN wells. Letters A-H are facies. MB 1 to MB 10 are unit tops.

4.1.3. Grain Angularity

Point count results for middle Bakken grain angularity of the Torgeson 2-15HS and Tomlinson 3-1HN wells are in Figure 33 and Figure 34. In both wells the grain angularity is mainly sub-angular to sub-rounded.

Torgeson 2-15HS has an overall trend of increasing percentage of rounded, angular, and very angular grains from the bottom to the top of the middle member. There is a peak in angular grains at 7950 ft. The thin section at 7929.5 ft did not have any rounded or well rounded grains.

Tomlinson 3-1HN has a larger percent of angular grains at 8641.15 ft and 8648.80 ft, with a decreasing percent of angular grains to the top and the bottom of the middle member. The percent of sub-angular grains generally increases from the top of the middle member to 8646.17 ft and then decreases to the bottom of the middle member. There appears to be more rounded grains in the upper half of the middle member than the lower half of the middle member.

A comparison in percent of well rounded and rounded grains between the Torgeson 2-15HS and Tomlinson 3-1HN wells is shown in Figure 35. Torgeson 2-15 HS has more well rounded and rounded grains from the top of the middle member to facies C (MB 3) than Tomlinson 3-1HN. Beneath facies C (MB 3) the two wells have varying amounts of well rounded and rounded grains.

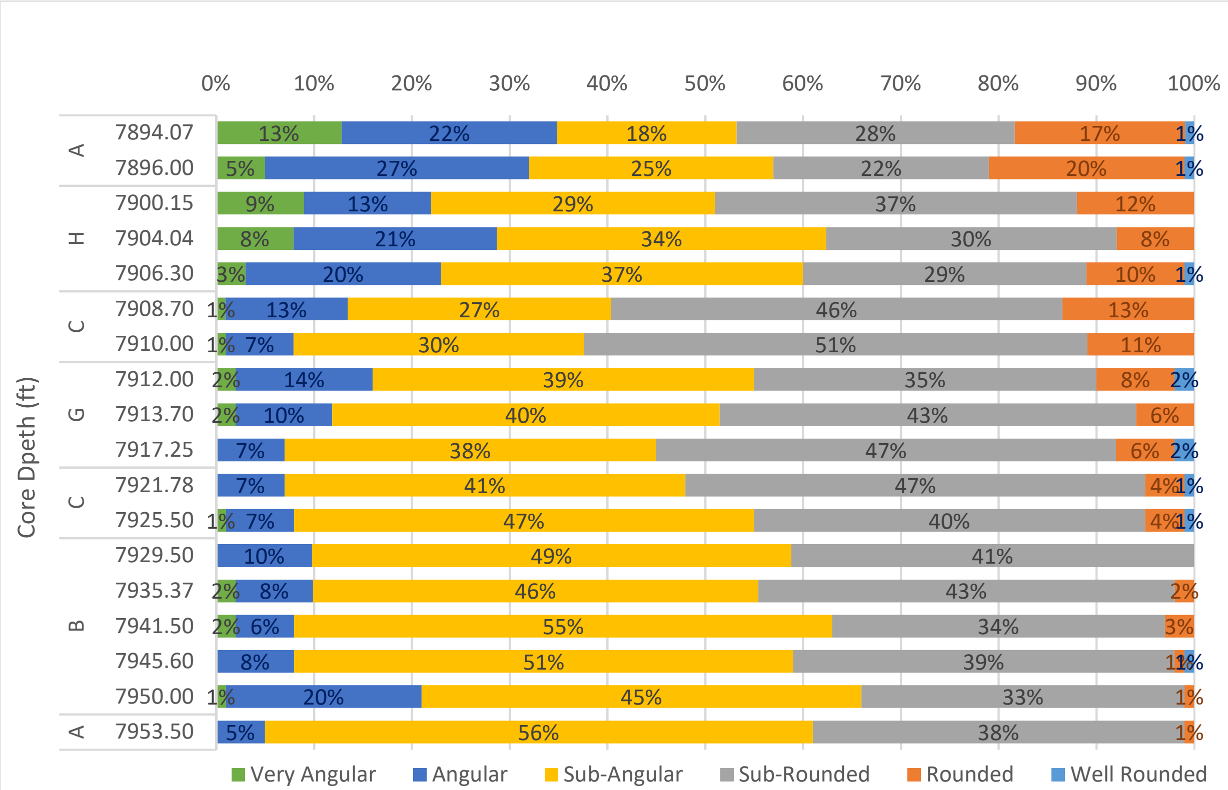


Figure 33. Torgeson 2-15HS middle Bakken grain angularity from point count data. Letters A through H are facies.

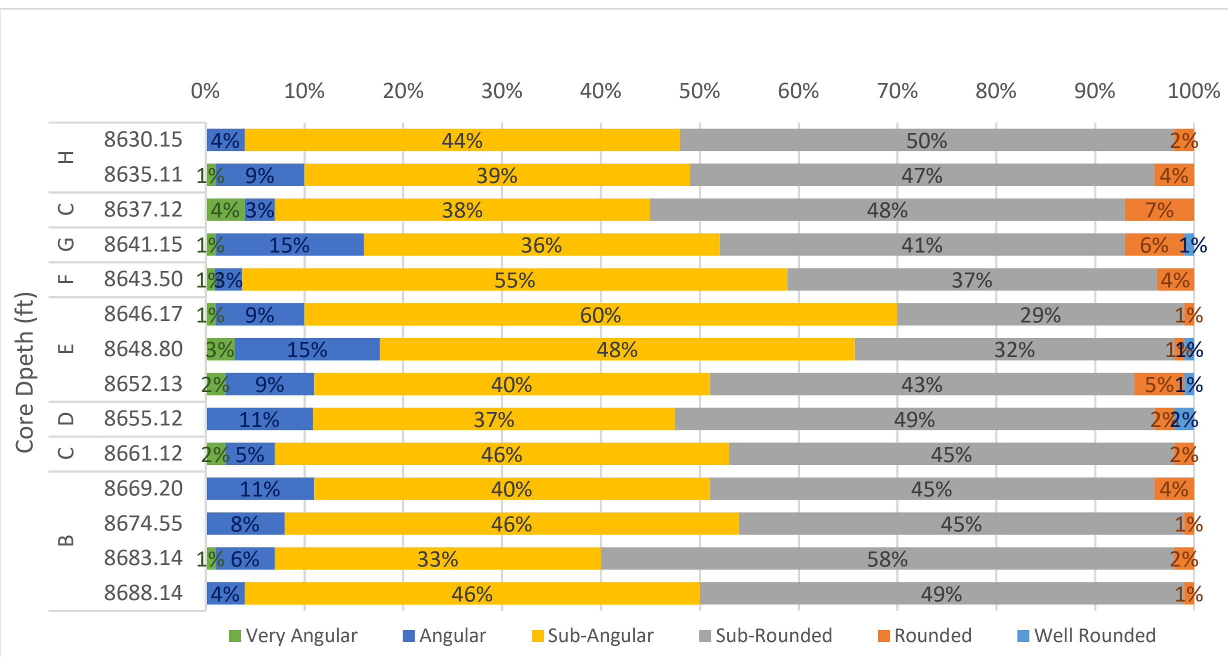


Figure 34. Tomlinson 3-1HN middle Bakken grain angularity from point count data. Letters A through H are facies.

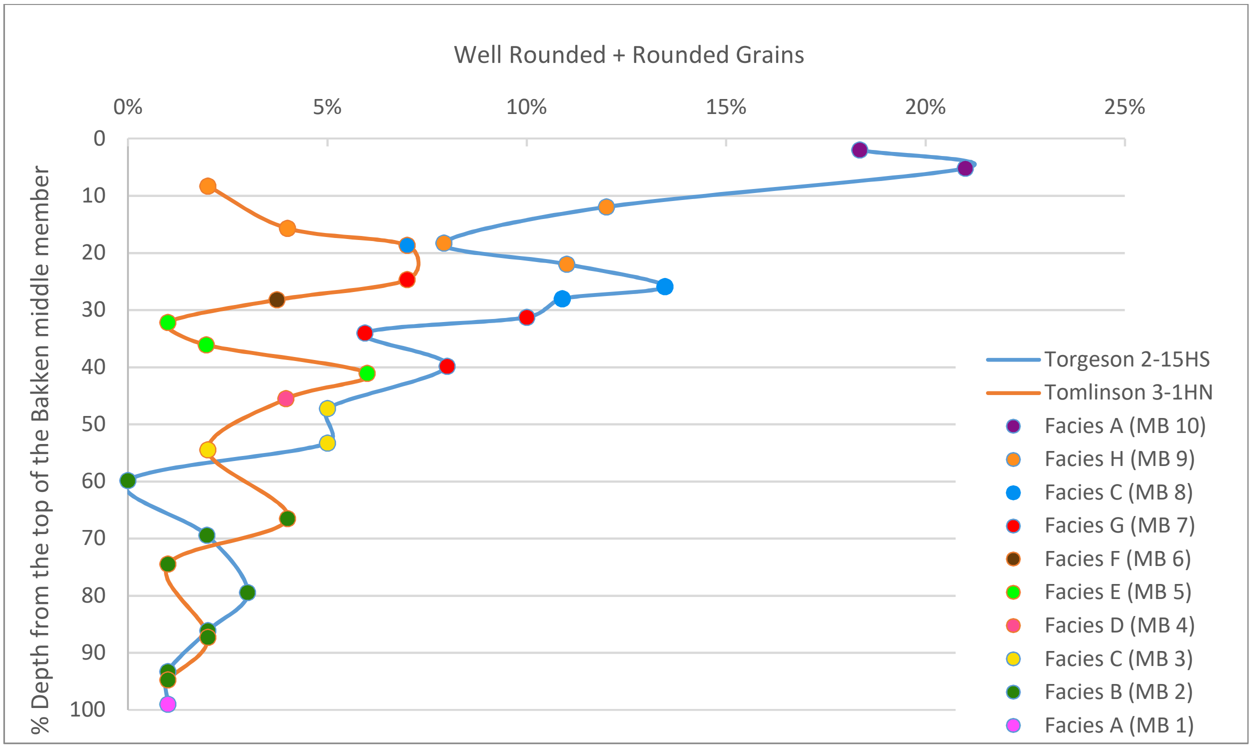


Figure 35. Comparison of well rounded and rounded grains in the Torgeson 2-15HS and Tomlinson 3-1HN wells. Letters A-H are facies. MB 1 to MB 10 are unit tops.

4.1.4. Provenance Plots

Grains from the point count were plotted on Dickinson and Suczek's (1979) ternary plots for provenance (Figure 36). Middle Bakken grains in the Torgeson 2-15HS and Tomlinson 3-1HN wells plot in the mature and stable craton interior continental block provenance portion of the ternary diagrams.

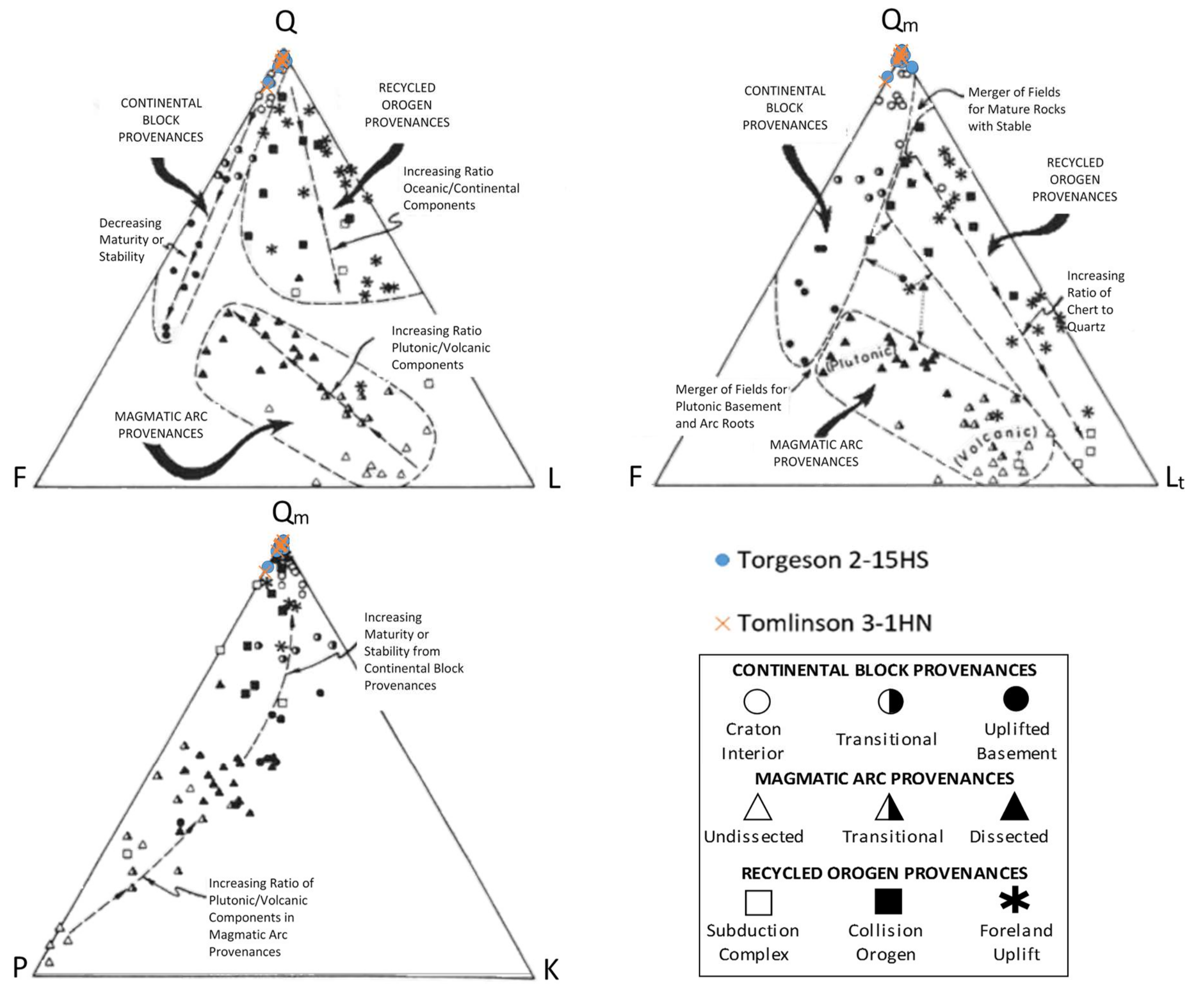


Figure 36. Middle Bakken provenance plots for the Torgeson 2-15HS and Tomlinson 3-1HN wells. F=feldspar; K=potassium feldspar; L=lithic fragments; Lt=total lithic fragments (L+Q_p); Q=total quartz, P=plagioclase feldspar; Q_m=monocrystalline quartz; Q_p=polycrystalline quartz (modified from Dickinson and Suczek, 1979).

4.2. Diagenesis

Images taken with the SEM showed types of cement as well as cross-cutting relationships that allowed interpretation of relative timing of cements. They also showed calcite replaced bioclasts, detrital apatite grains, and at least one illite grain (Figure 42 to Figure 45). Opaque minerals were mainly pyrite with some titanium oxides that could be rutile or anatase.

Figure 37 shows angular quartz grains, cement inclusions, and porosity. The angular edges of quartz grains indicate syntaxial quartz overgrowth. Inclusions of quartz and dolomite cement within calcite cement indicate that quartz grains were partially dissolved, then dolomite cement filled in some of the open pore space, then dolomite partially dissolved, then calcite cement filled in some of the open pore space. Pyrite seems to be the most recent diagenetic precipitate.

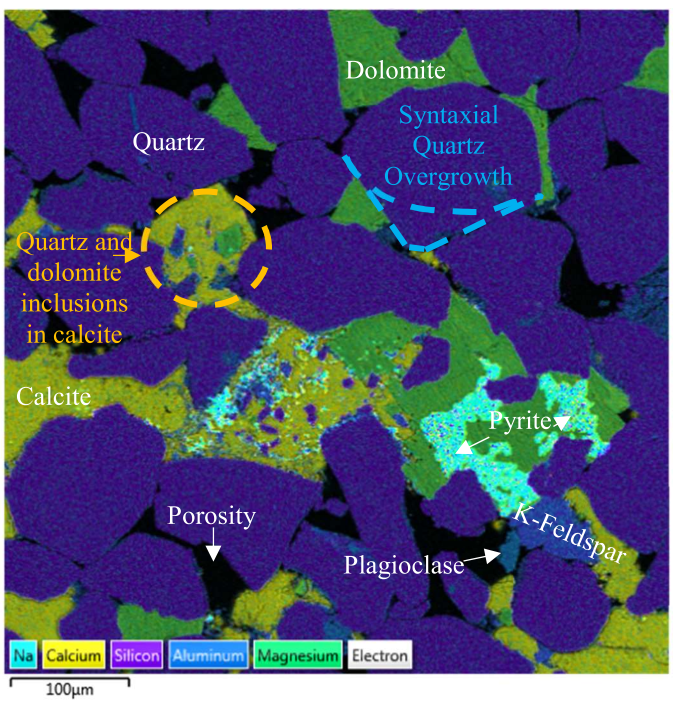


Figure 37. Syntaxial quartz overgrowth (blue dashed line), partial dissolution of quartz and feldspar, and inclusions of quartz and dolomite in calcite cement (orange dashed line) in Torgeson 2-15HS facies G at 7917.25 ft core depth.

Figure 38 shows partially dissolved quartz grains and different types of cement. The shape of some quartz grains indicates partial dissolution of quartz and filling of resulting pore space by cement.

Figure 39 shows an overall image of facies G parallel laminated sandstone. Pyrite seems to be the most recent diagenetic precipitate.

Figure 40 shows partial dissolution of quartz grains and a calcite recrystallized or replaced bioclast. Figure 41 shows interparticle void space possibly filled with hydrocarbons in facies G parallel laminated sandstone. It was difficult to determine if the void space is filled with hydrocarbons because empty pore space and hydrocarbons in void space both show up as carbon using the SEM. It appears that clusters of quartz grains protected their interparticle void space from being filled with cement. The image also shows two detrital apatite grains. Figure 42 shows another detrital apatite grain. Figure 43 shows a mineral of illite.

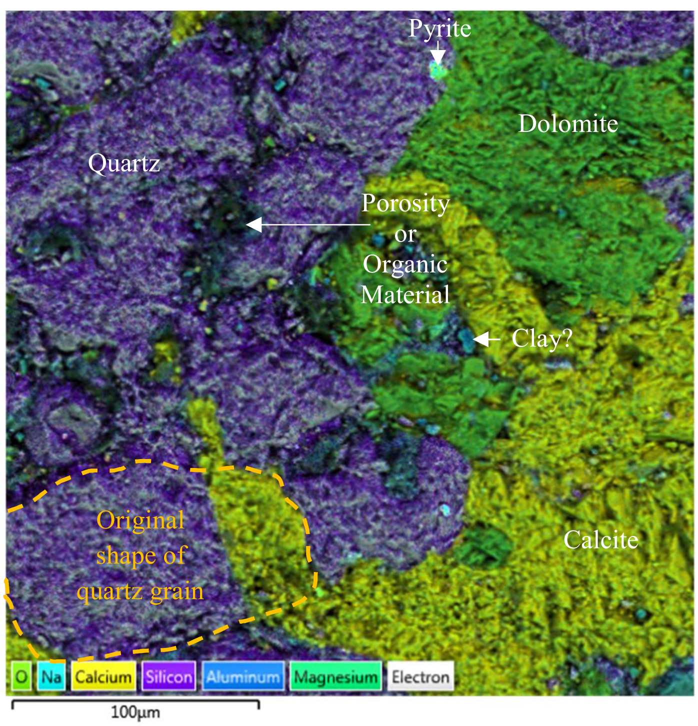


Figure 38. Partially dissolved quartz grain filled with calcite cement. Approximate shape of original grain is outlined in orange. Tomlinson 3-1HN facies G at 8641.15 ft core depth.

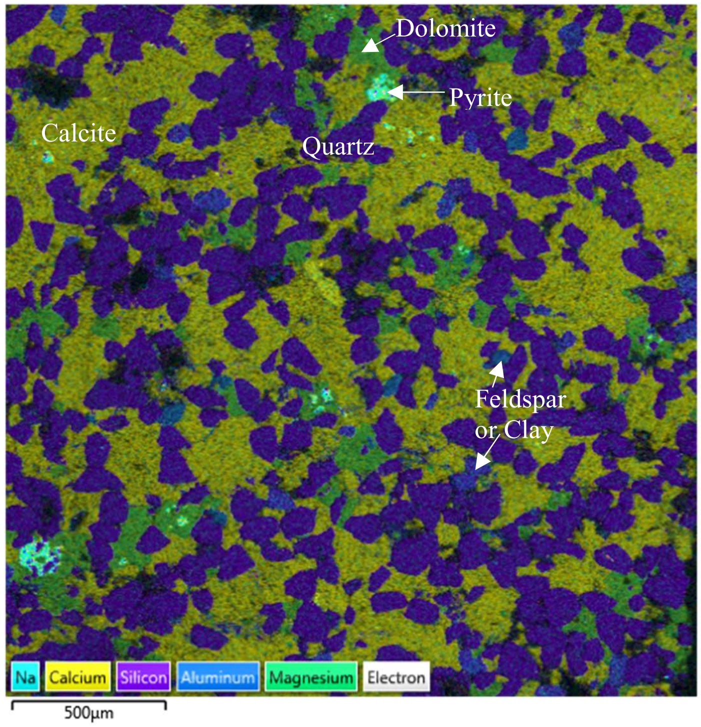


Figure 39. Overall image of Tomlinson 3-1HN facies G at 8641.15 ft core depth.

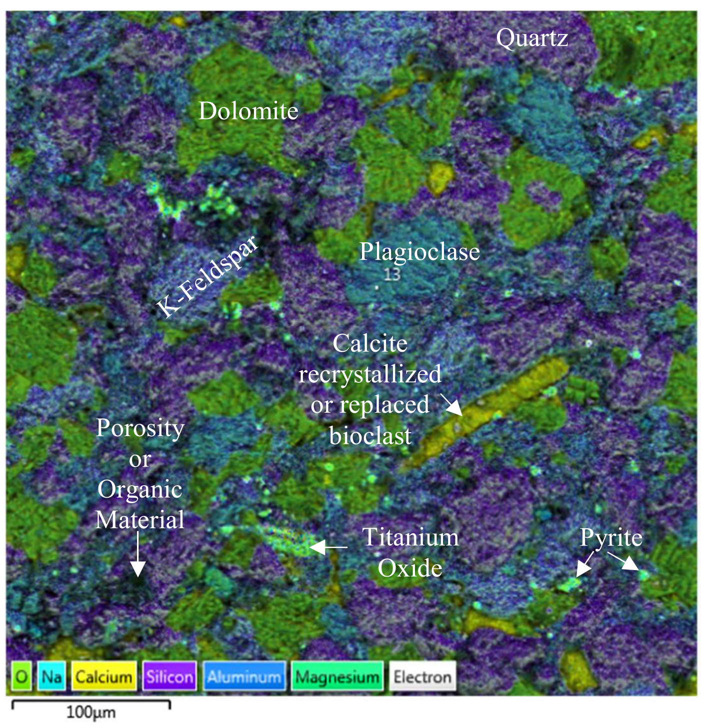


Figure 40. Partial dissolution of quartz and a calcite recrystallized or replaced bioclast in Tomlinson 3-1HN facies C at 8661.12 ft core depth. The titanium oxide could be rutile or anatase.

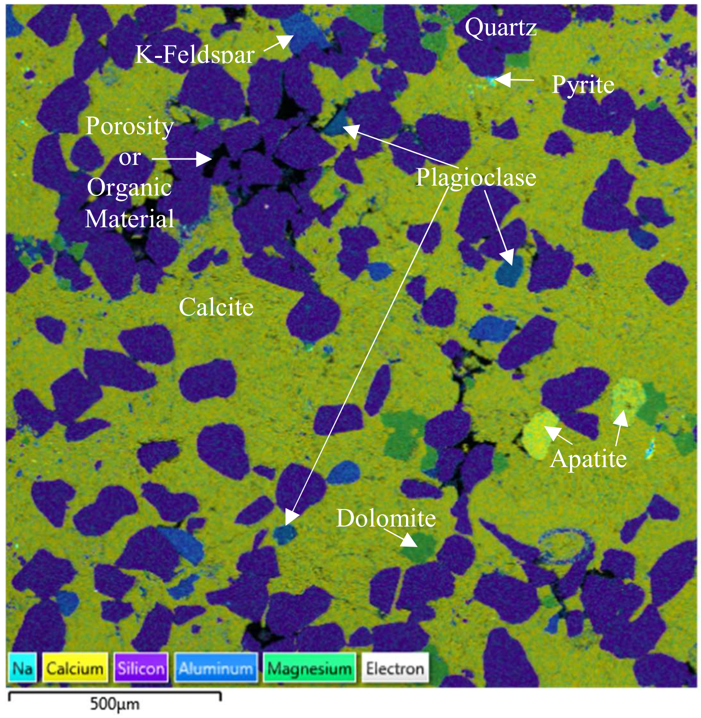


Figure 41. Interparticle void space possibly filled with hydrocarbons in Torgeson 2-15HS facies G at 7917.25 ft core depth. It appears that clusters of quartz protected their interparticle void space from being filled with cement.

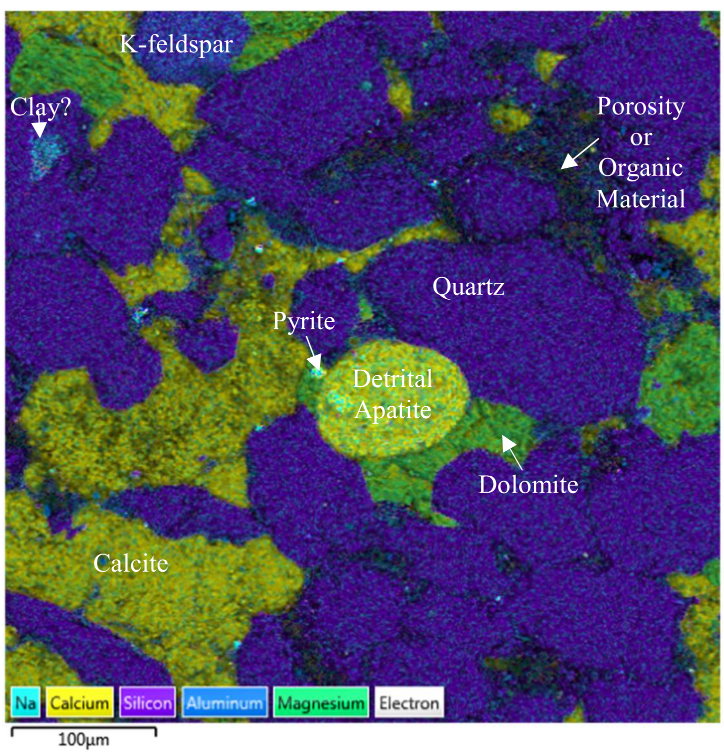


Figure 42. Detrital apatite grain in Tomlinson 3-1HN facies G at 8641.15 ft core depth.

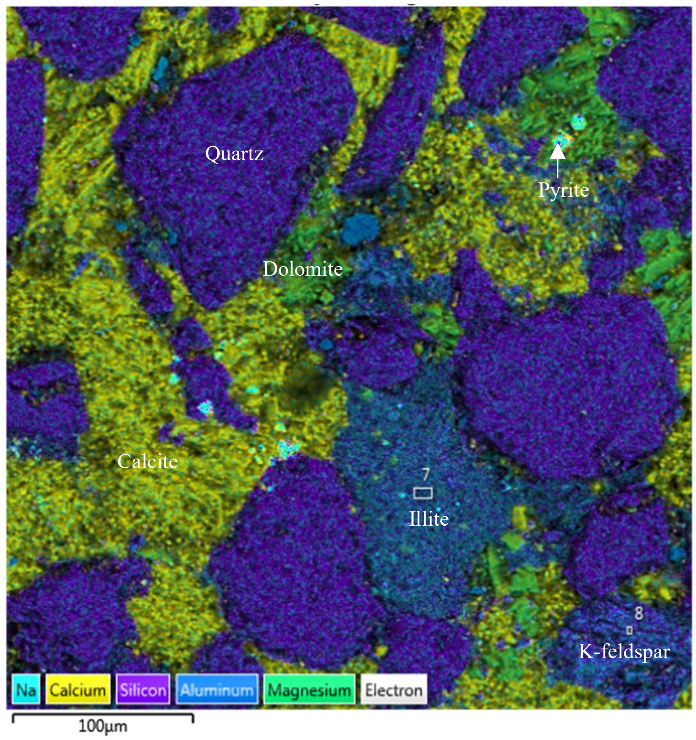


Figure 43. Illite grain in Tomlinson 3-1HN facies G at 8641.15 ft core depth.

Figure 44 shows partial dissolution of potassium feldspar, or feldspar altered to clay, followed by dolomite cement infill in some of the pore space, partial dissolution of dolomite cement, and infill of calcite cement. Pyrite appears to be the most recent diagenetic precipitate.

Figure 45 shows the relative iron concentrations for minerals in Figure 44. The iron concentration shows two zoned dolomite rhombohedra that have four stages of growth with the first and third stages being non-iron rich and the second and fourth stages being iron rich.

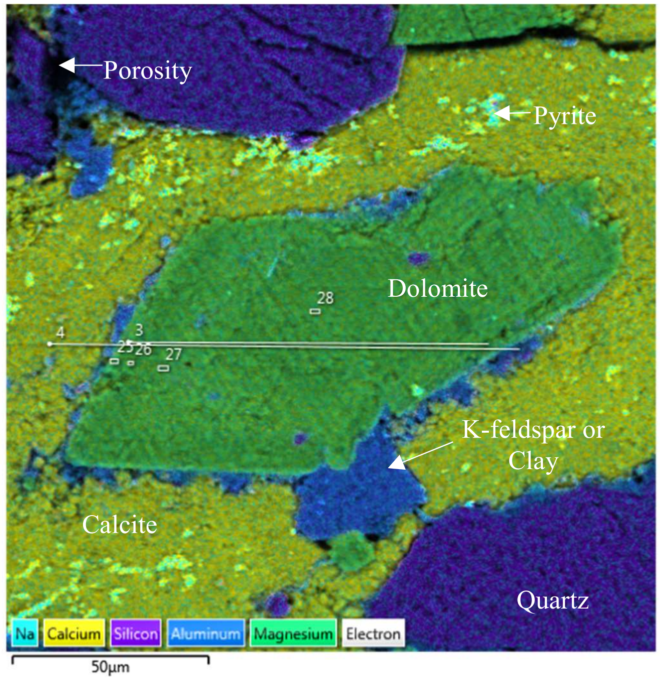


Figure 44. Partial dissolution of potassium feldspar (or feldspar altered to clay), infill by dolomite cement, then infill by calcite cement in Torgeson 2-15HS facies G at 7917.25 ft core depth. Gray numbers and lines delineate areas where individual elemental compositions were taken.

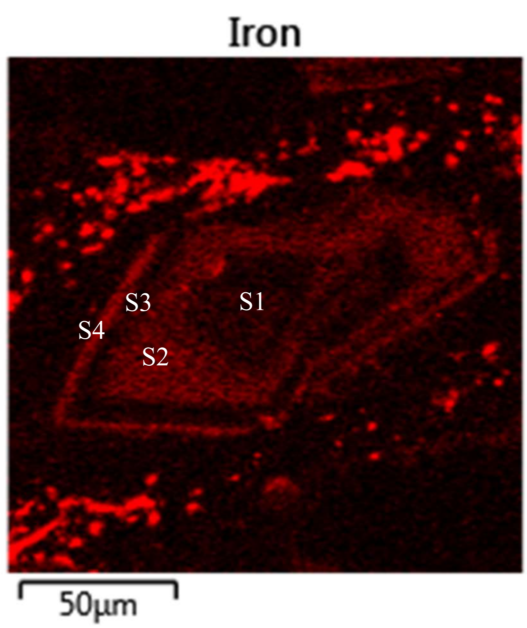


Figure 45. Image showing relative iron concentration (red color) of the dolomite rhombohedra from Figure 44 in Torgeson 2-15HS facies G at 7917.25 ft core depth. Pyrite is the bright red and iron rich dolomite is the duller red color. Zonation of the two dolomite rhombohedra in the middle of the image shows four different stages of dolomite growth labeled S1 to S4. S1 and S3 are non-iron rich. S2 and S4 are iron rich.

Dolomite compositions from four different thin sections were taken with the SEM and compared to find similar types of dolomite cement (Table I). There appears to be three types of dolomite: (1) ferroan dolomite with ~10% iron; (2) ferroan dolomite with ~5-10% iron; and (3) dolomite with less than 5% iron.

Table I. Dolomite cement compositions for four thin sections in the Torgeson 2-15HS and Tomlinson 3-1HN wells. Similar types of cement compositions were grouped by amount of iron. There appear to be three types of dolomite: (1) ferroan dolomite with>10% iron; (2) ferroan dolomite with 5-10% iron; and (3) dolomite with <5% iron. Spectrum number refers to SEM image number.

Well	Tomlinson 3-1HN	Tomlinson 3-1HN	Tomlinson 3-1HN	Tomlinson 3-1HN	Tomlinson 3-1HN	Tomlinson 3-1HN	Tomlinson 3-1HN	Tomlinson 3-1HN	Tomlinson 3-1HN	Tomlinson 3-1HN	Torgeson 2-15HS	Torgeson 2-15HS	Torgeson 2-15HS	Torgeson 2-15HS
Slide #	5	5	7	7	11	11	11	11	11	11	12	12	12	12
Core Depth (ft)	8641.15	8641.15	8646.17	8646.17	8661.12	8661.12	8661.12	8661.12	8661.12	8661.12	7917.25	7917.25	7917.25	7917.25
Spectrum #	1	2	29	30	15	16	17	18	21	22	25	26	27	28
Facies	G	G	E	E	C	C	C	C	C	C	G	G	G	G
Element	Weight Percents													
O	59.69	41.04	44.47	40.45	45.21	44.40	41.18	46.38	30.87	34.93	51.37	50.39	48.4	52
Ca	20.50	36.77	33.23	35.98	31.10	30.88	33.41	30.24	49.93	37.61	26.91	31.92	30.63	30.7
Mg	13.99	11.13	20.72	15.87	19.25	18.59	17.67	18.46	15.47	15.38	11.66	15.58	14.03	15.13
Fe	2.72	10.48	0.57	5.99	3.21	3.28	5.02	2.96	0.74	2.77	7.13	1.14	5.48	1.55
Si	2.66	0.45	0.63	0.91	0.60	1.27	0.88	0.79	1.59	4.46	1.51	0.33	0.61	0.23
Al	0.31	0.06	0.20	0.40	0.20	0.55	0.45	0.32	0.60	2.98	0.63	0.12	0.24	0.01
K	0.09	0.03	0.09	0.19	0.15	0.53	0.20	0.16	0.35	0.74	0.36	0.06	0.14	0.04
S	0.03	0.02	0.04	0.08	0.09	0.23	0.16	0.07	0.20	0.39	0.36	0.39	0.25	0.28
P	0.02	0.00	0.00	0.00	0.03	0.02	0.02	0.04	0.00	0.00	0.00	0.01	0.02	0.00
Ti	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
Na	0.00	0.00	0.04	0.13	0.16	0.15	0.28	0.08	0.10	0.39	0.06	0.05	0.21	0.04

Legend: Ferroan dolomite with >10% iron; Ferroan dolomite with 5-10% iron; Dolomite with <5% iron

4.3. Subsurface Mapping

The Torgeson 2-15HS and Tomlinson 3-1HN well logs were tied-in with their core descriptions modified from Hofmann et al. (2014) work and divided into facies A through H. Since some facies occur more than once in the middle member, the two wells were subsequently divided into stratigraphic units middle Bakken 1 (MB 1) through middle Bakken 10 (MB 10). The Torgeson 2-15HS and Tomlinson 3-1HN wells were then used as type logs (Figure 46) to correlate all other wells in the study area. Tables showing unit tops of all wells correlated in this study are in Appendix D.

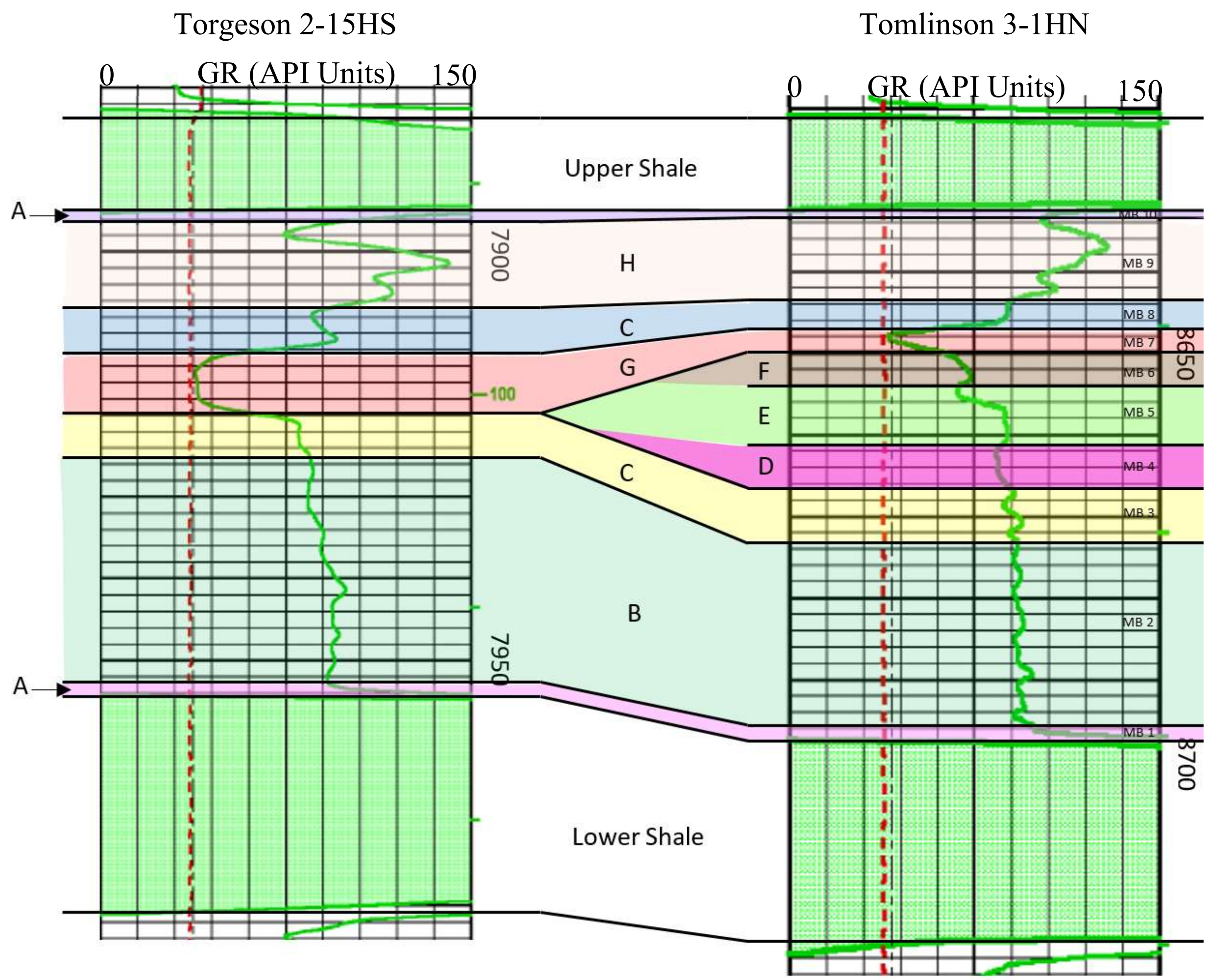


Figure 46. Torgeson 2-15HS (left) and Tomlinson 3-1HN (right) type wells for correlating well logs. Well log response (green line) is gamma ray on a scale of 0 to 150 API units. Lithofacies division modified from Hofmann et al. (2014). Refer to Figure 20 for description of facies A-H. MB 1 to MB 10 denote each stratigraphic unit correlated within the middle member of the Bakken Formation.

4.3.1. Cross-Sections

Three cross-sections were constructed to show thickness changes across the study area and to show how well units correlate across the study area. Locations of the cross-sections are in Figure 47. The third cross-section, C-C’, shows the test wells and will be discussed in section 4.3.3.

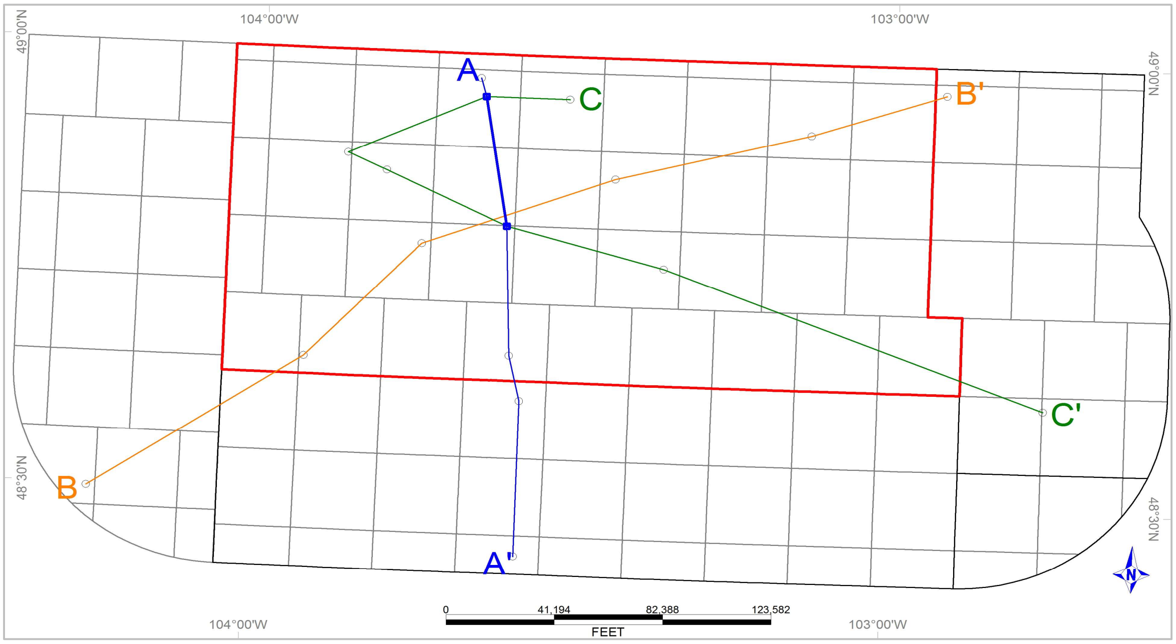


Figure 47. Location of cross-sections in the study area. Divide County is outlined in red. Other county lines are black. Township lines are gray.

Cross-section A-A’ (Figure 48) is oriented north to south. It consists of six wells, including the Torgeson 2-15HS and Tomlinson 3-1HN wells, and spans 37.35 miles. Facies D (micro cross-laminated silty sandstone), E (ripple cross-laminated sandstone), and F (bioturbated sandstone) do not correlate across the entire study area. The middle member of the Bakken thickens from the southern portion of the study area to the central portion of Divide County, then thins towards the US border. This thickness trend along the cross section is also shown in the isopach map of the middle member (Figure 54) in following sections.

Cross-section B-B’ (Figure 49) is oriented southeast to northeast and consists of six wells spanning 70.37 miles. The middle member thickens from the southwest corner of the study area to the northeast corner of the study area. Cross-section C-C’ shows the Torgeson 2-15HS and Tomlinson 3-1HN type wells with the five test wells used to check quality of prior correlations, and will be discussed in section 4.3.3 Test Wells.

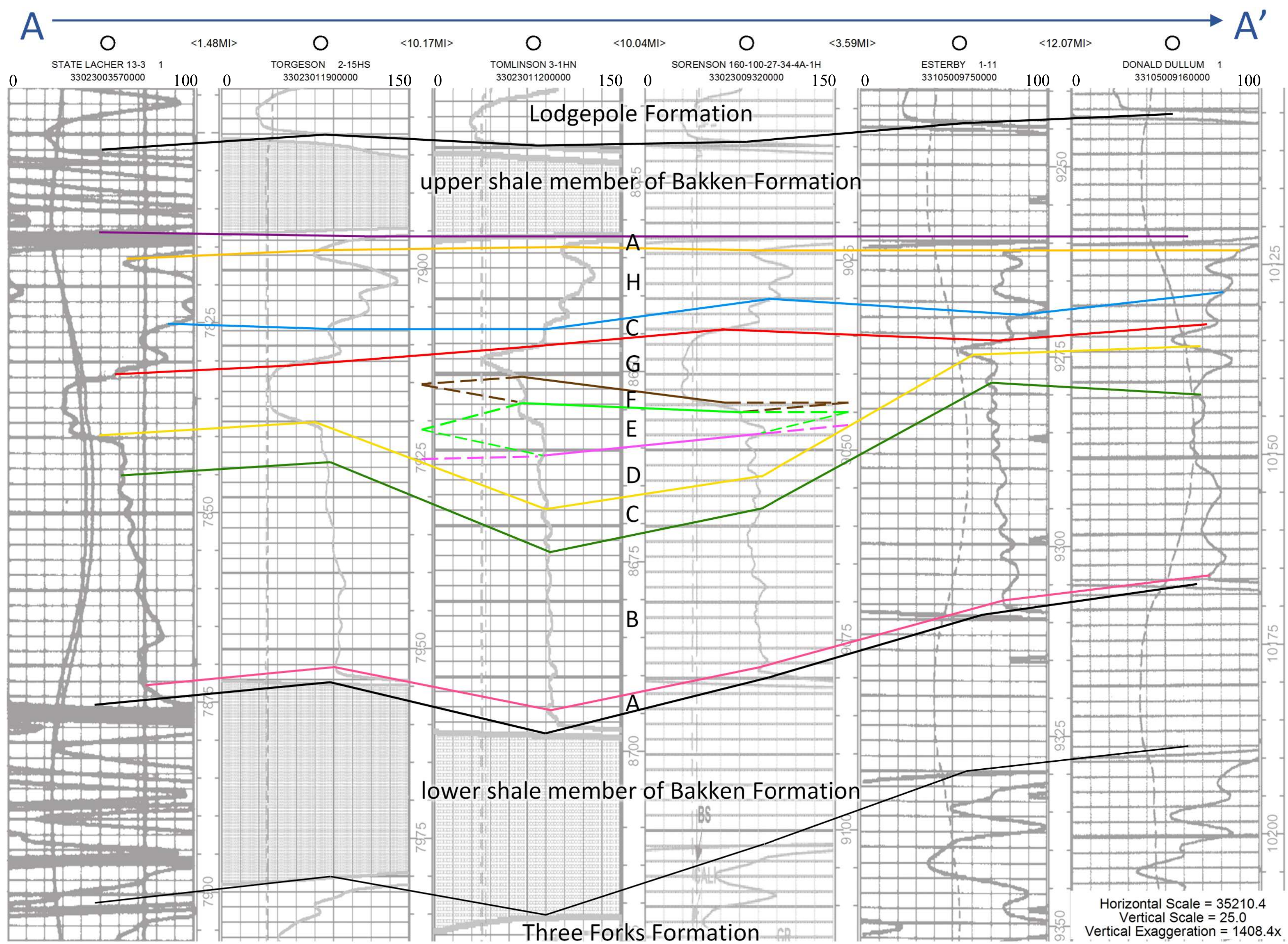


Figure 48. Cross-section A-A' with facies A-H. Datum is top of the middle member of the Bakken Formation. Log curves are gamma ray in API.

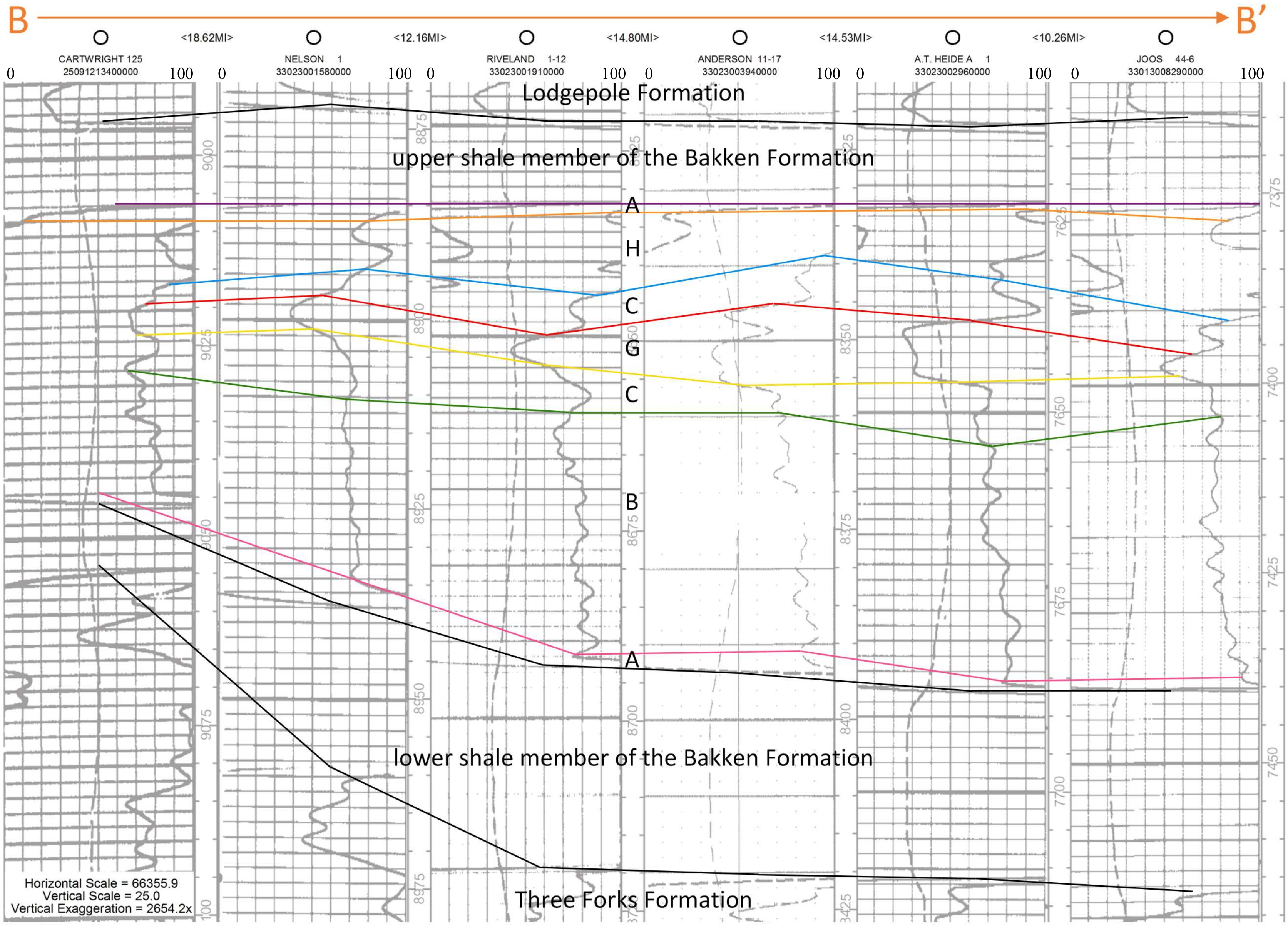


Figure 49. Cross-section B-B' with facies A-H. Datum is top of the middle member of the Bakken Formation. Log curves are gamma ray in API.

4.3.1. Structure Contour Maps

Structure contour maps for all members and units of the Bakken Formation were created in Petra. All of the maps look similar. The structure map for the top of the lower shale member of the Bakken Formation is shown in Figure 50 as an example of what all the structure maps look like. The lower shale dips to the south, as do all other Bakken Formation members and units. The map's interpreted location of the Nesson Anticline is included as a reference structure (Figure 50).

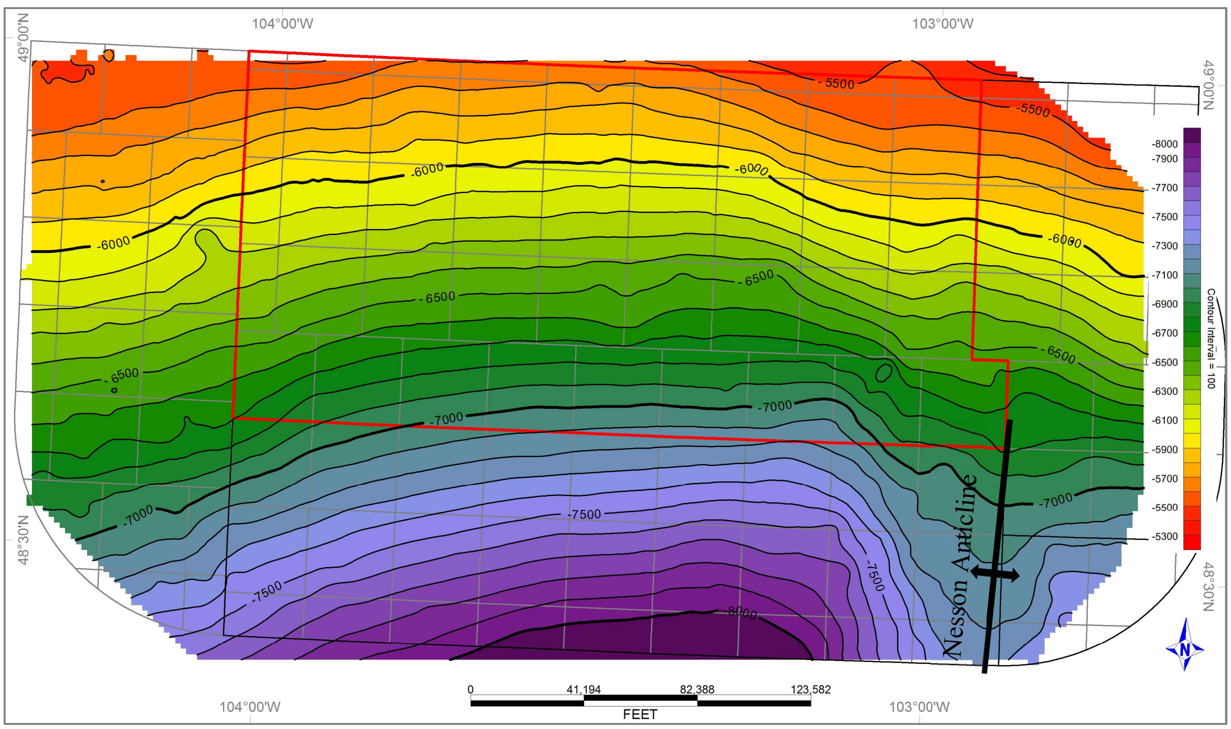


Figure 50. Structure map of the top of the lower shale member of the Bakken Formation. Divide County is outlined in red. Other county borders are black. Township lines are gray.

4.3.2. Isopach Maps

Isopach maps were created from unit tops in Petra with the program's kriging function. Isopach maps were created for the Prairie Formation, Bakken Formation, informal members of the Bakken Formation, and units within the middle member of the Bakken Formation.

4.3.2.1. Prairie Formation, Bakken Formation, and Bakken Informal Members

An isopach of the Prairie Formation is in Figure 51. Isopachs of the Bakken Formation and its three informal members are in Figure 52 to Figure 55.

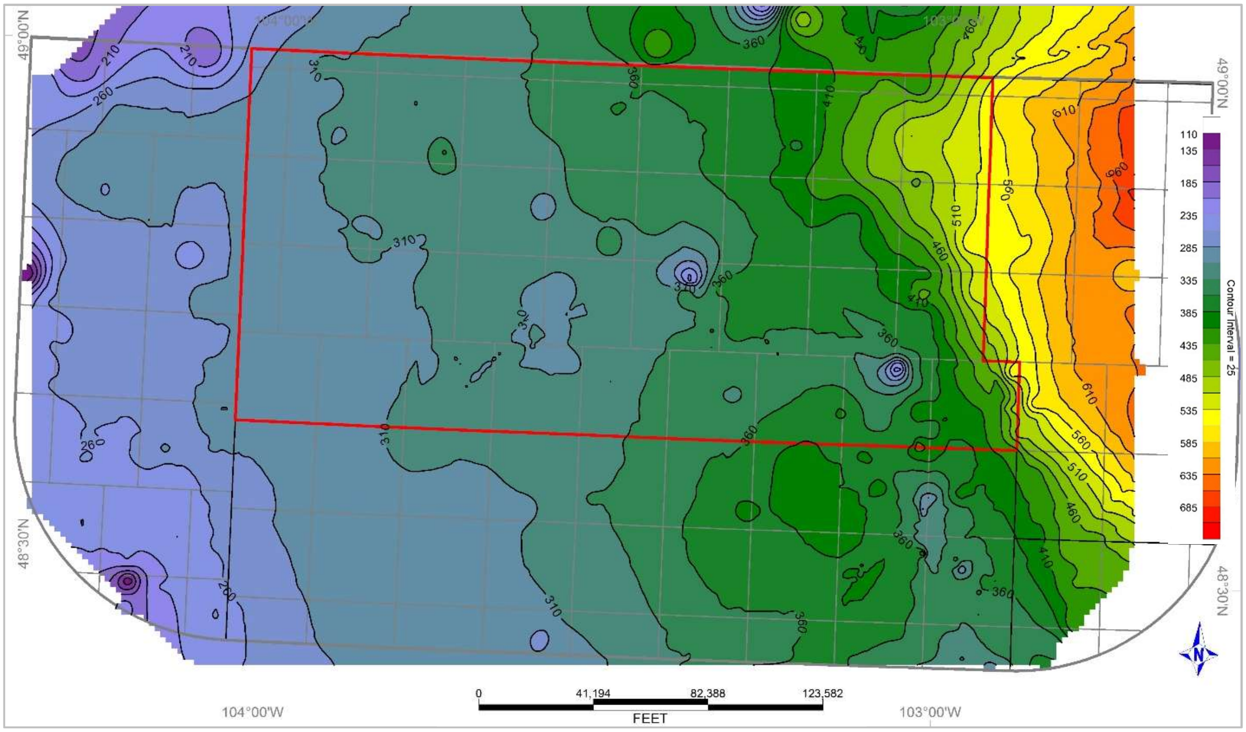


Figure 51. Isopach of the Middle Devonian Prairie Formation. Divide County is outlined in red. Other county borders are black. Township lines are gray.

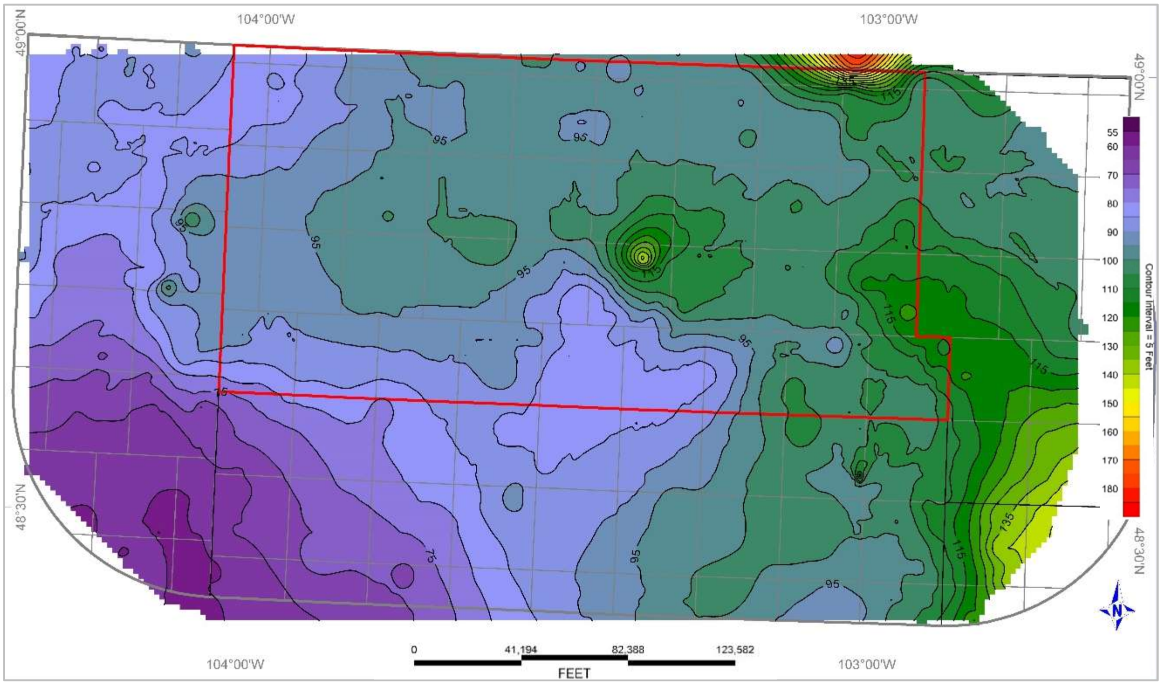


Figure 52. Isopach of the Bakken Formation. Divide County is outlined in red. Other county borders are black. Township lines are gray.

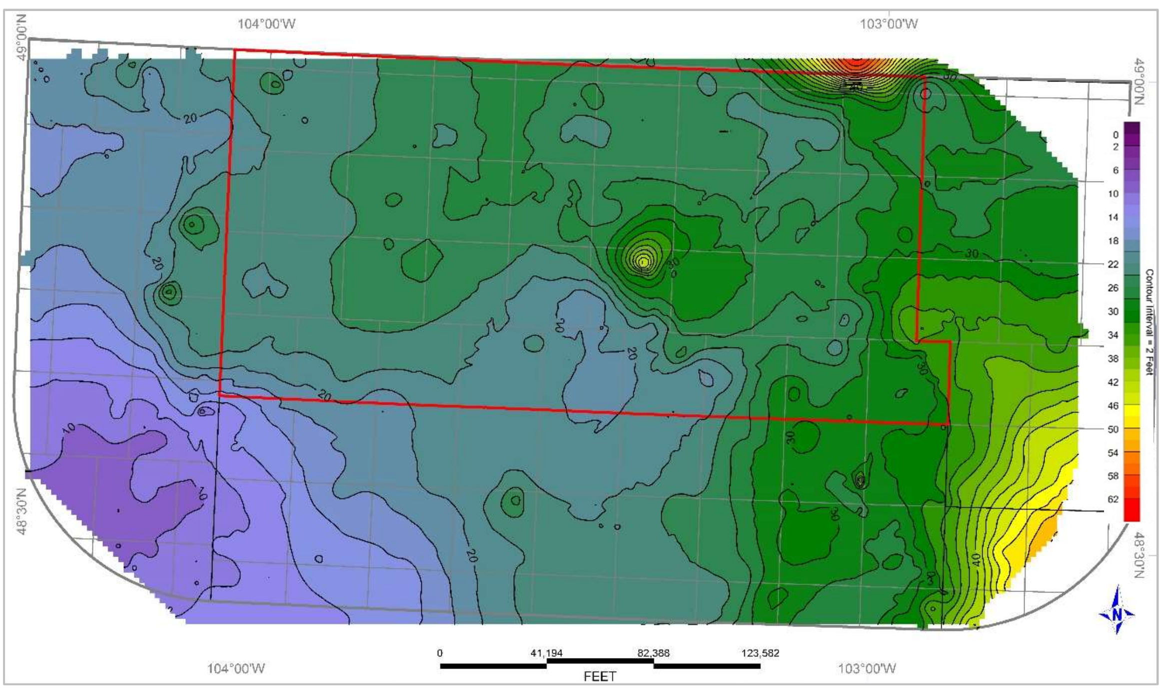


Figure 53. Isopach of the lower shale member of the Bakken Formation. Divide County is outlined in red. Other county borders are black. Township lines are gray.

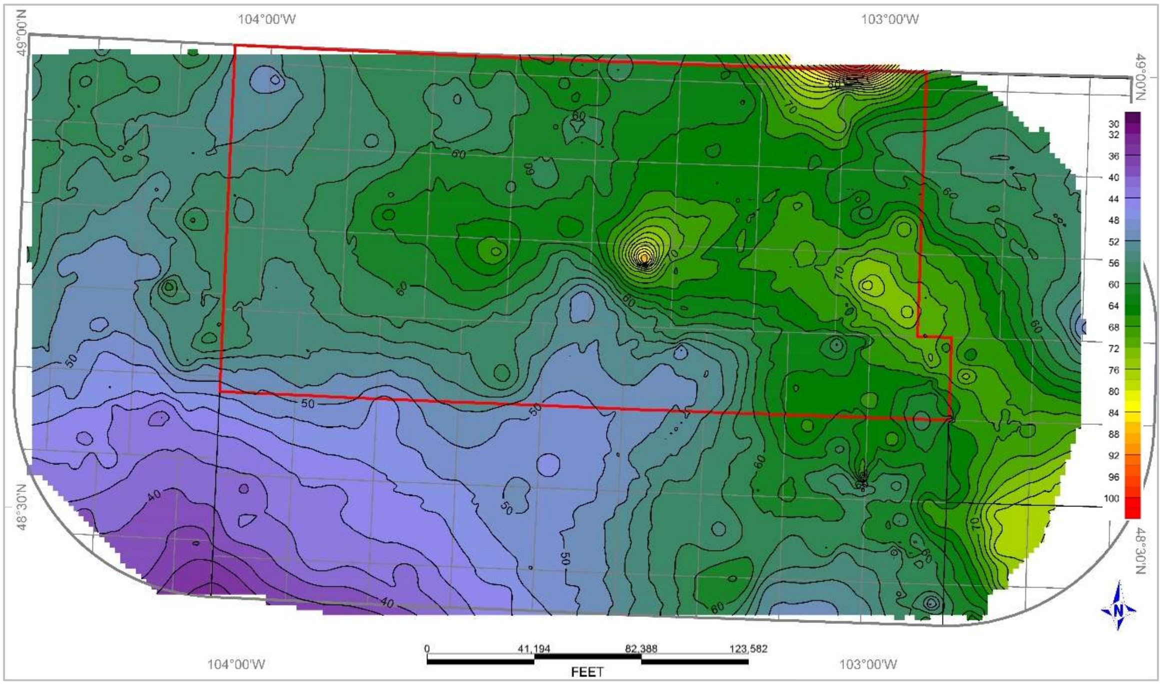


Figure 54. Isopach of the middle member of the Bakken Formation. Divide County is outlined in red. Other county borders are black. Township lines are gray.

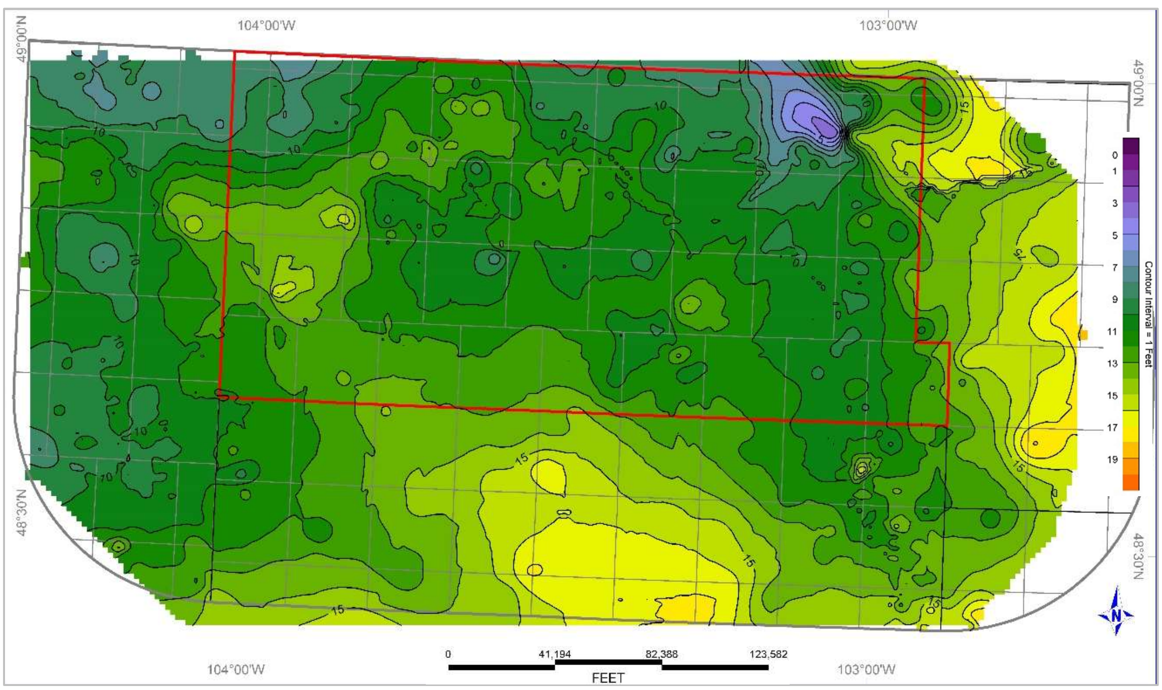


Figure 55. Isopach of the upper shale member of the Bakken Formation. Divide County is outlined in red. Other county borders are black. Township lines are gray.

The Prairie Formation is 110 ft thick in the western portion of the study area and thickens to 685 ft in the eastern portion of the study area. A Prairie Formation thin in the middle of Divide County (Figure 51) coincides with lower shale and middle member Bakken thicks (Figure 53 and Figure 54).

The Bakken Formation ranges from 60 ft to 135 ft thick in the study area (Figure 52). Overall thickness appears to increase from the southwest to the northeast portion of the study area. There is a general thick trend from the southeast corner to the northeast corner and slightly northwest up to the Canadian border.

The lower shale member of the Bakken Formation ranges from 10 ft to ~50 ft thick in the study area (Figure 53). Overall thickness appears to increase from the southwest corner to the northeast corner of the study area, with an additional thick area in the southeast corner. A local thick exists near the middle of Divide County.

The middle member of the Bakken Formation ranges from 34 ft to 86 ft thick in the study area (Figure 54). Overall thickness appears to increase from the southwest corner to the northeast corner of the study area. There is an additional thickness trend from the southeast corner to the north and slightly northwest. A local thick exists in near the middle of Divide County.

The upper shale member of the Bakken Formation ranges from ~5 ft to 17 ft thick in the study area (Figure 55). Overall thickness appears to increase from the northern to the southern portions of the study area. There are two additional thick trends. The first thick trend begins at the south-central portion of the study area and trends to the northwest before terminating halfway through Divide County. The second thickness trend is from the southeastern corner to the northeastern corner of the study area. A local thin near the northeast corner of the study area may be an artifact as there were no wells to correlate in the area of the local thin.

4.3.2.2. Units of the middle member of the Bakken Formation

Isopachs of units within the middle member of the Bakken Formation are in Figure 56 to Figure 60. Unit tops from MB 1 to the bottom of MB 7 (clean sand facies G) did not correlate well across the study area and were therefore lumped together (Figure 56). Individual isopach maps for these units MB 1 to MB 6 can be viewed in Appendix C.

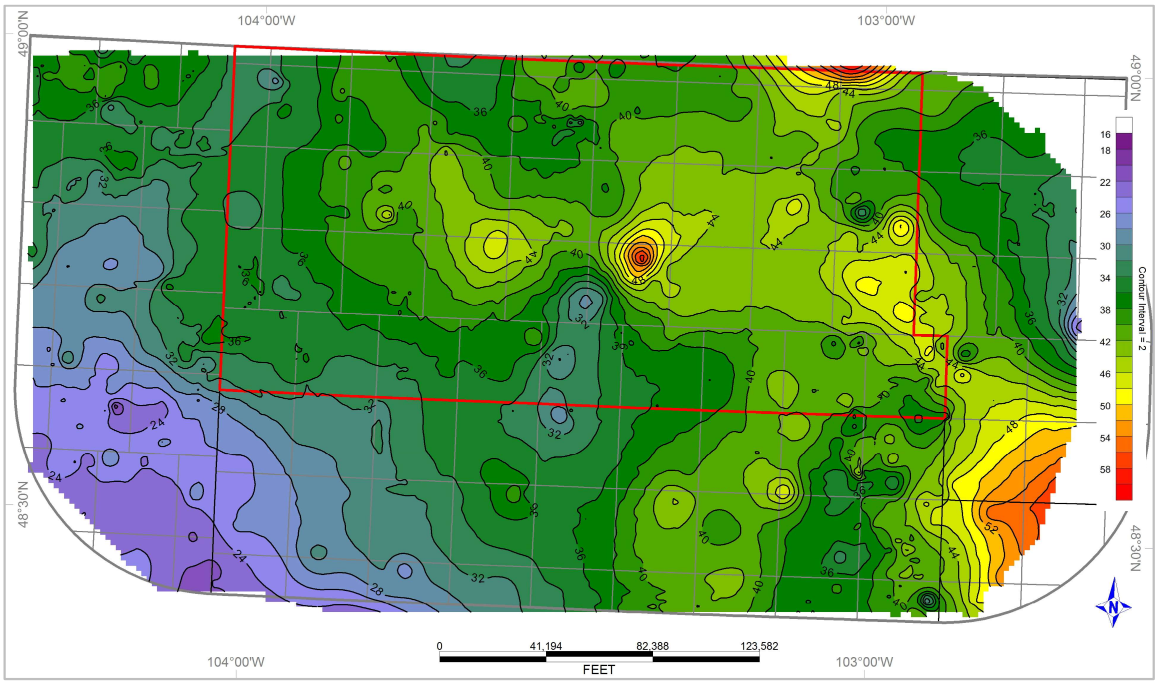


Figure 56. Isopach from the top of the lower shale member to the bottom of facies G (unit MB 7) in the middle member. Divide County is outlined in red. Other county borders are black. Townships lines are gray.

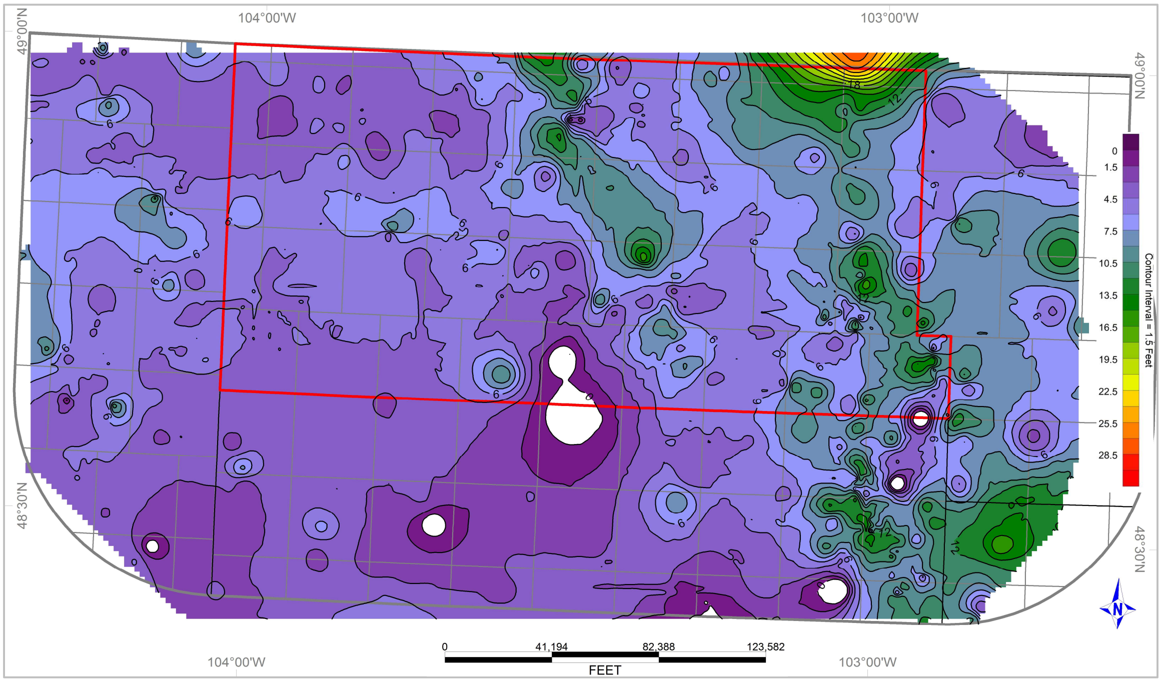


Figure 57. Isopach of unit MB 7 (facies G parallel laminated sandstone) of the middle member. Divide County is outlined in red. Other county borders are black. Township lines are gray.

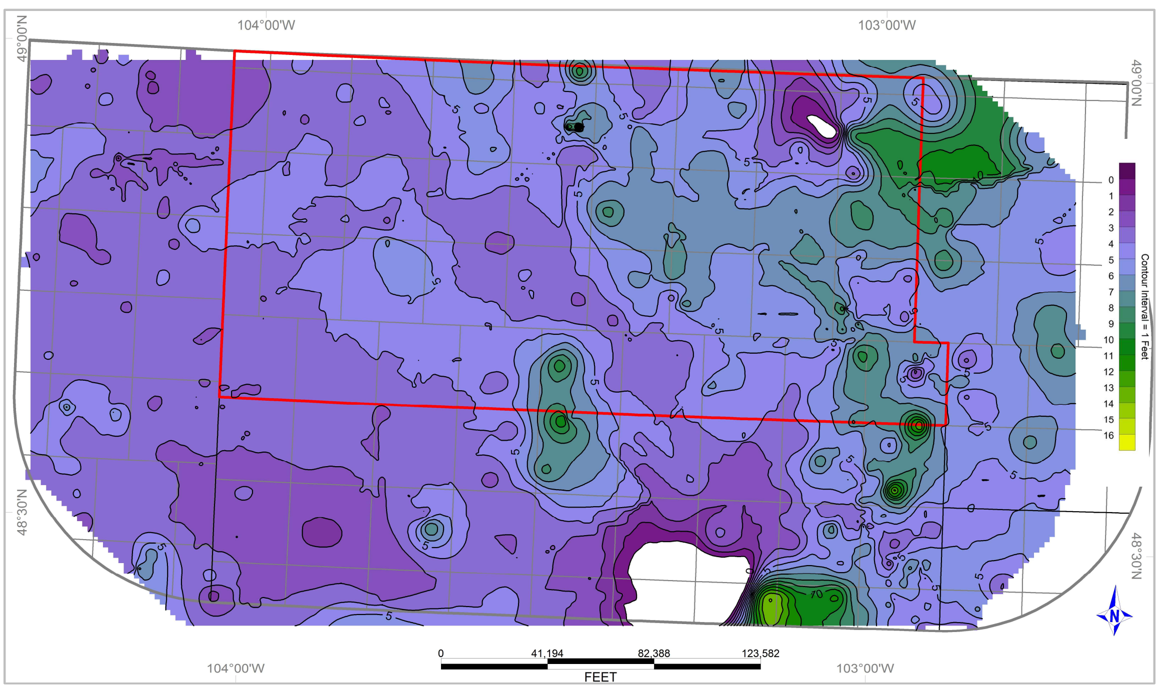


Figure 58. Isopach of MB 8 (facies C parallel laminated silty sandstone) of the middle member. Divide County is outlined in red. Other county borders are black. Township lines are gray.

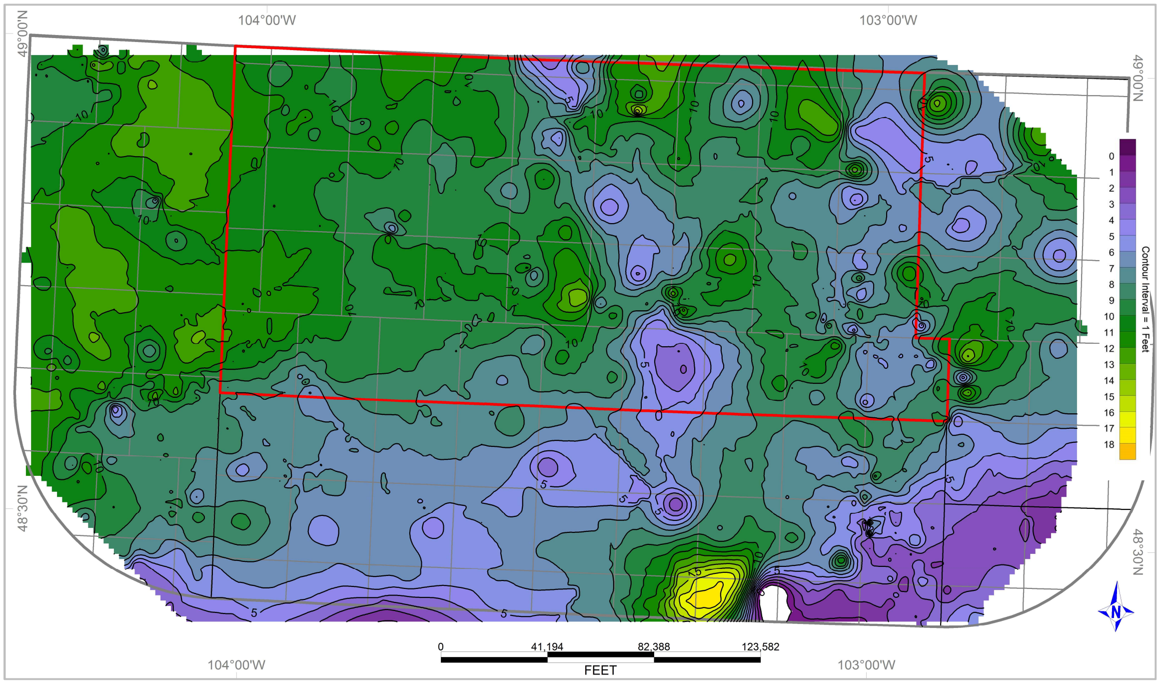


Figure 59. Isopach of MB 9 (facies H bioturbated interbedded mudstone-sandstone/mudstone and sandstone) of the middle member. Divide County is outlined in red. Other county lines are black. Township lines are gray.

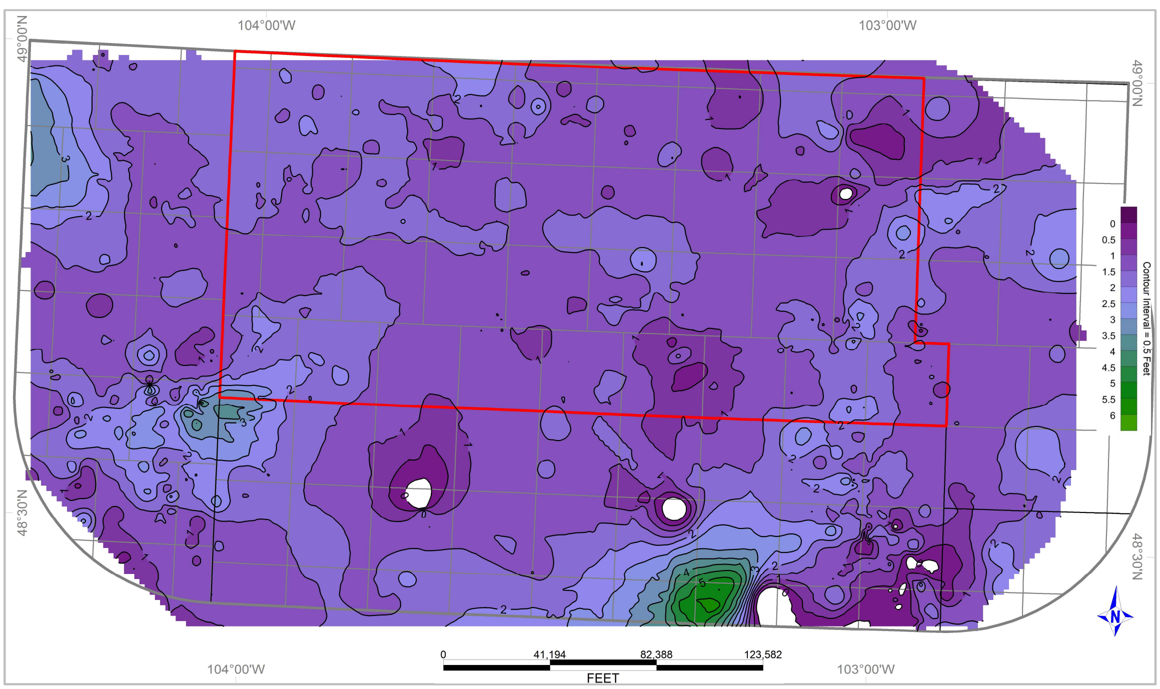


Figure 60. Isopach of MB 10 (facies A bioclastic muddy siltstone) of the middle member. Divide County is outlined in red. Other county lines are black. Township lines are gray.

Thickness of facies from top of the lower shale member to the bottom of middle member clean sand facies G (unit MB 7) ranges from ~22 ft to 60 ft in the study area (Figure 56). Overall thickness appears to increase from the southwest corner to northeast corner of the study area. There is an additional thickness trend beginning at the southeastern corner of the study area and trending to the northwest and west. A local thick exists near the middle of Divide County.

Thickness of unit MB 7 parallel laminated sandstone of the middle member ranges from ~0 ft to ~20 ft in the study area (Figure 57). There are thickness trends from the west side to the central portion of the study area along a horizontal line going through the middle of Divide County, and from the north-central and northeastern sides to the southeastern side of the study area.

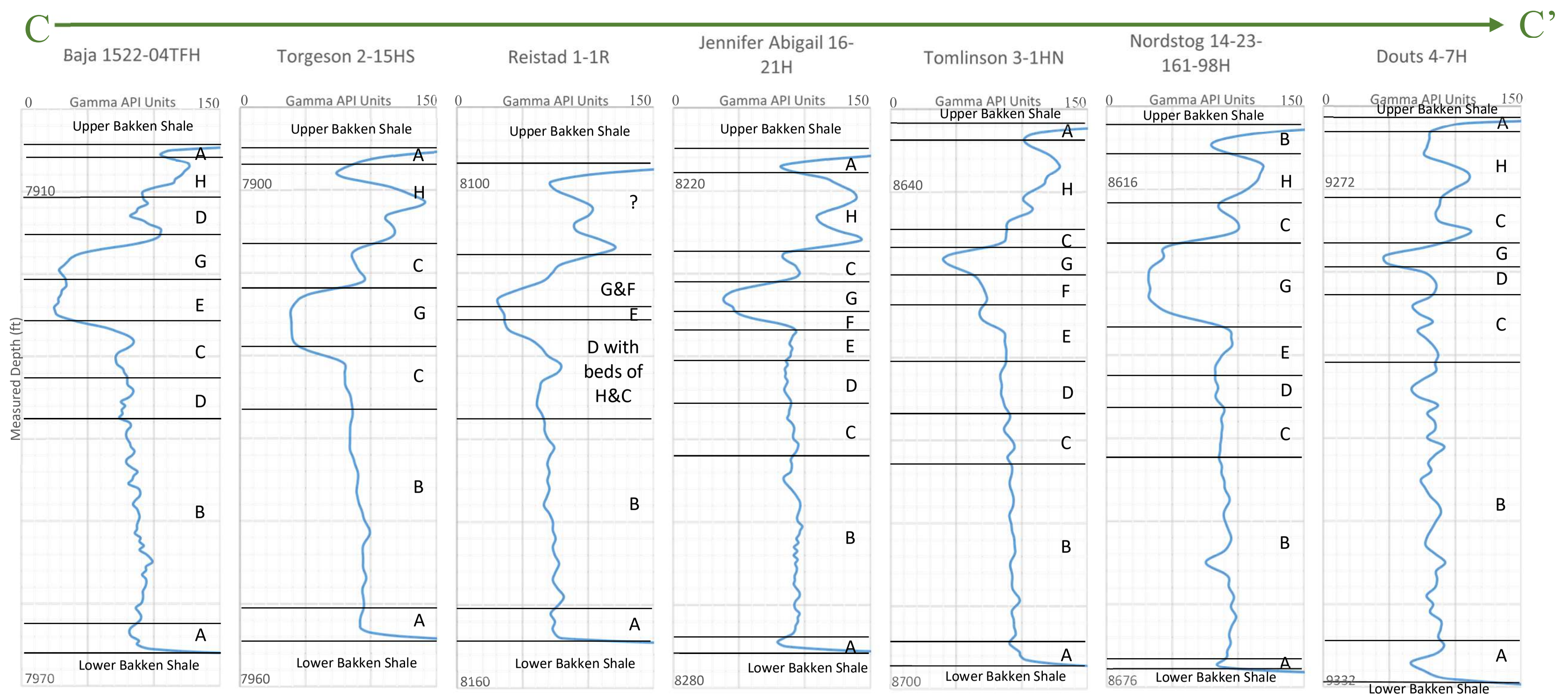
Thickness of unit MB 8 parallel laminated silty sandstone of the middle member ranges from ~0 ft to ~13 ft in the study area (Figure 58). The unit is thickest in the eastern side of the study area.

Thickness of unit MB 9 bioturbated interbedded mudstone-sandstone/mudstone and sandstone of the middle member ranges from ~0 ft to 18 ft in the study area (Figure 59). Overall thickness appears to increase from the southern to northern sides of the study area. A local thick occurs near the south-central portion of the study area. A trend of thinness begins at the south-central side of the study area and curves upwards to the northeast until the southern edge of Divide County, then curves slightly northwest to the northern edge of the study area.

Thickness of unit MB 10 bioclastic muddy siltstone of the middle member ranges from ~0 ft to 6 ft in the study area (Figure 60). There is a local thick near the south-central side of the study area.

4.3.3. Test Wells

After correlating wells and making maps, five additional core descriptions were made available to the study. These additional core descriptions were tied-in to their respective well logs and used to check quality of prior correlations and to compare variation of lithofacies. The comparison of core description to log tie-ins for the two type wells and five additional test wells are in cross-section C-C' (Figure 61).



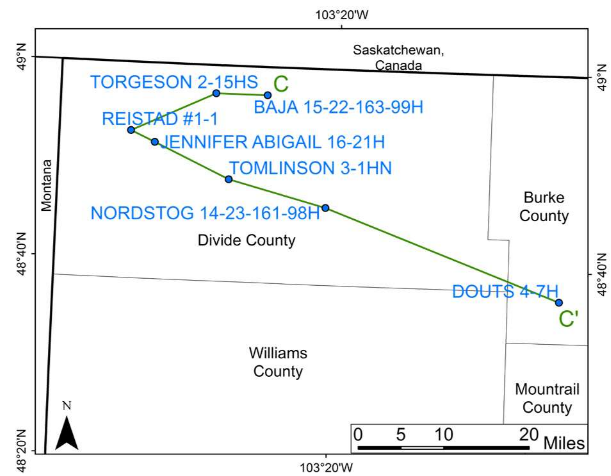


Figure 61. Cross-section C-C' of the Torgeson 2-15HS and Tomlinson 3-1HN type wells and the five test wells showing heterogeneity of facies below the clean sand (facies G). Facies A through H divisions were modified and tied in from Hofmann et al. (2014) core descriptions provided by SM Energy.

Figure 61 shows that tops above facies G correlate well throughout the seven SM Energy wells, but tops below facies G lack gamma log responses that are recognizable across all seven wells, making them nearly impossible to correlate. As a result of this poor correlation, all units below facies G were lumped together to create isopach maps (Figure 56).

5. Discussion

5.1. Optical Petrography

Grains in the thin sections are mainly sub-angular to sub-rounded and range in size from fine-grained to silt/clay sized, with all facies except facies G having over 50% silt/clay sized grains. The overall best facies for the amount of porosity, cement, and quartz grains are sandstone facies E, F, and G. This study's sandstone facies (E, F, and G) have been recognized by previous authors (Nordquist, 1953; Sandberg and Hammond, 1958; Christopher, 1961; Hayes, 1985; Thrasher, 1987; Smith and Bustin, 1997; Pitman et al., 2001; LeFever, 2007; Canter et al., 2011; Egenhoff et al., 2011; Angulo and Buatois, 2012). The Torgeson 2-15HS and Tomlinson 3-1HN wells have very similar mineralogy and grain size. The Torgeson 2-15HS well has a little more quartz, larger-grained clasts, and well rounded, rounded, angular, and very angular grains than the Tomlinson 3-1HN well. The small variations in the two wells' facies and lithology indicate similar depositional environments and similar sediment sources, with the Torgeson 2-15HS well being slightly more proximal to the sediment source.

Apatite is a calcium phosphate that can form within organic-rich mud (Pufahl, 2010). Shallow water granular phosphorite dominated ancient epeiric platforms with prominent coastal upwelling and the phosphorite factory operated across a wide depositional spectrum. Storms were the most important agent in reworking pristine phosphorite into granular deposits and in transporting and redepositing winnowed phosphatic clasts (Pufahl, 2010). Anhydrite/fluorapatite grains were seen in the point count from facies A (MB 1) to facies F in the Tomlinson 3-1HN well. Apatite grains seen in the sandstone facies of the Tomlinson 3-1HN well using the SEM were rounded and not surrounded by mud or micrite. This indicates that apatite was formed in organic-rich muds and then winnowed, ripped-up, and redeposited by storm events.

Clay content in the Torgeson 2-15HS facies G thin section at 7917.25 ft seems much higher than it should be compared to the other sandstone facies in the Torgeson 2-15HS and Tomlinson 3-1HN wells. The reason for higher clay has not been discovered, but a possible source of error could be point counting hydrocarbon staining as clay.

The point count porosity overestimated the porosity compared to the well log porosity, which could be explained by well log resolution. Well logs generally have a two foot resolution, so units smaller than two feet are not discernable. If the point count is completed in a higher porosity unit a few centimeters thick, then the count overestimates porosity for the entire section of core as compared to log porosity.

Provenance plots indicate that middle member grains come from a stable craton interior continental block provenance. This makes sense because the Williston Basin of North Dakota during Bakken deposition was within the continent of Laurussia.

5.2. Sedimentology

Smith and Bustin (1997), LeFever (2007), and Hofmann et al. (2014) interpret the middle Bakken as marine, whereas Angulo (2010) interprets the upper and lower middle Bakken as open marine and the middle of the middle Bakken as a brackish-water marginal-marine embayment. This study did not include core description, sequence stratigraphy, or ichnology, and the Torgeson 2-15HS and Tomlinson 3-1HN were the only two wells whose cores were viewed and whose thin sections were point counted. For these reasons, general inferences on possible type of depositional environments were made, but no definitive interpretations were made.

The amount of quartz, coarser-grained clasts, and well rounded and rounded grains in the thin sections indicate overall shallowing from the lower shale member to facies G of the middle member and then overall deepening from facies G to the top of the middle member. Facies G is the highest energy facies and is interpreted to represent the most proximal facies to a shoreline, possibly as a bay barrier. The non-correlative facies D (micro laminated siltstone and silty sandstone), E (ripple cross-laminated sandstone), and F (bioturbated sandstone) show two small fining upwards sequences from facies C (MB) to facies G in the Tomlinson 3-1 HN and may represent a more distal location than facies G or represent deposition in a marginal marine embayment or similar environment.

Cross-section A-A' shows a thickening of middle member sediments where facies D, E, and F exist. In addition, areas with facies D, E, and F coincide with areas of minor but laterally extensive Prairie Formation evaporite dissolution (Figure 62). This indicates that facies D, E, and F were deposited throughout the study area, but largely eroded before deposition of the overlying facies G. Facies D, E, and F were only preserved in areas with ongoing Prairie Formation dissolution.

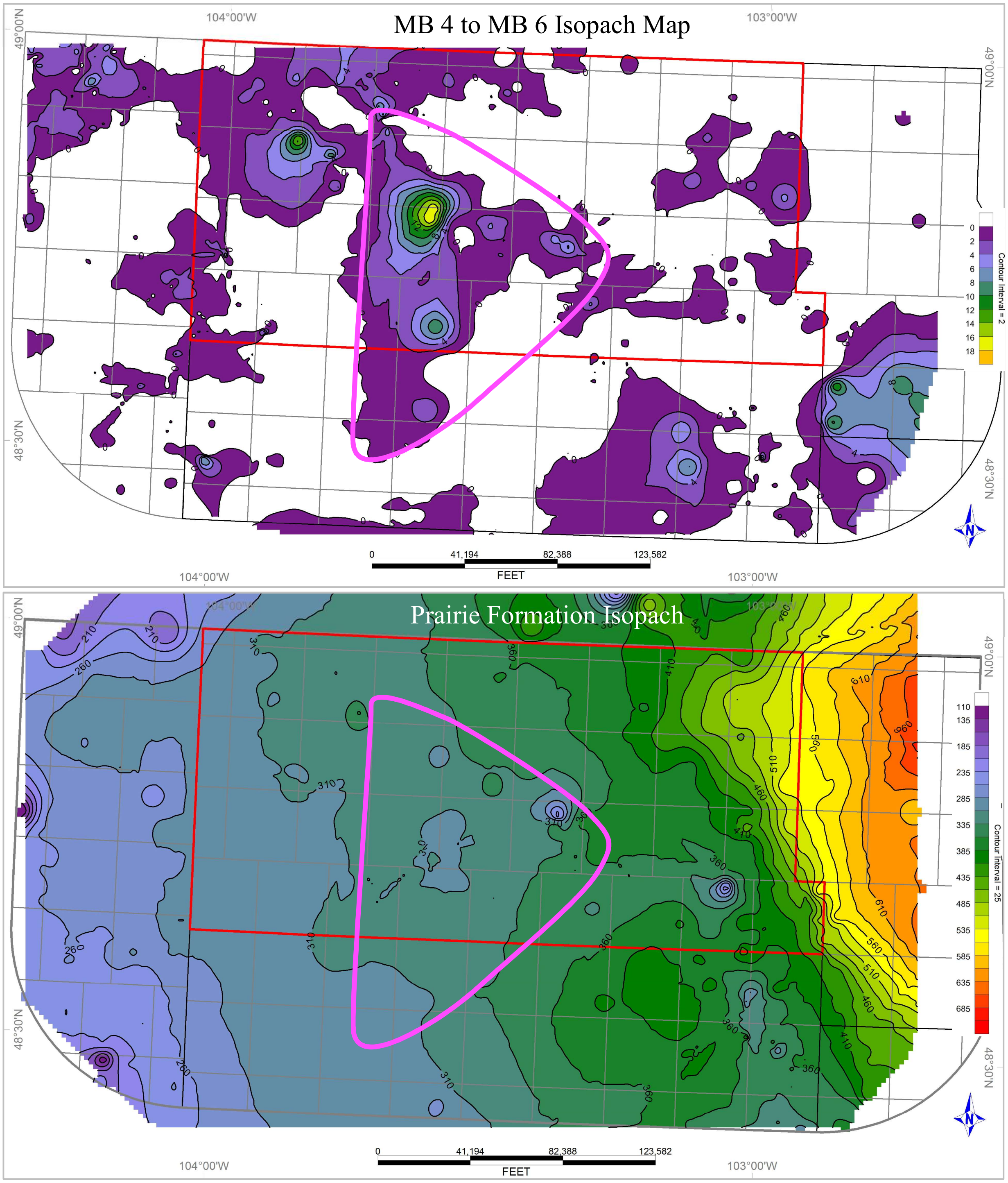


Figure 62. Isopach maps showing that the extent of non-correlative facies D, E, and F coincide with areas of minor but laterally extensive Prairie Formation dissolution. One of these coinciding areas is outlined in pink in both isopach maps. The 16 foot thick area inside the pink outline in the MB 4 to MB 6 isopach map is the location of the Tomlinson 3-1HN well. Divide county is outlined in red. Other county borders are black. Township lines are gray.

5.3. Diagenesis

There appears to be three types of dolomite cement whose compositions correlate between the Torgeson 2-15HS and Tomlinson 3-1HN wells. The similarity of cements indicate that similar fluids and resulting diagenesis happened in both wells, which are 10.17 miles apart. This falls in line with the Pitman et al. (2001) findings that middle member diagenesis was fairly continuous until oil emplacement. The upper and lower Bakken shale members acted as impermeable layers that prevented movement of fluids through the middle member, which resulted in the diagenesis of the middle member being fairly continuous up until oil emplacement in the Late Cretaceous (Pitman et al., 2001). Similarity of cements between the two wells in this study and throughout the Williston Basin (Pitman et al., 2001) indicate that diagenesis was more regional than local.

Preliminary results from SEM work shows that possible relationships of cement from oldest to youngest are:

1. Syntaxial quartz overgrowth
2. Feldspar alteration to clay
3. Partial dissolution of quartz and feldspar/clay
4. Dolomite cement
5. Partial dissolution of dolomite cement
6. Calcite cement
7. Partial dissolution of dolomite and calcite cement
8. Precipitation of pyrite

Pitman et al. (2001) suggested that middle member secondary quartz came from the chemical compaction of framework grains during early burial. They also suggested that late diagenetic alterations involving dissolution of earlier carbonate cements and precipitation of ferroan dolomite cement were caused by changes in temperature and pore-fluid chemistry associated with progressive burial. The most likely source of iron for ferroan dolomite was given as sulfides in the shale members above and below the middle member (Pitman et al., 2001).

In burial dolomitization, compaction-driven flow drives magnesium-rich waters from shale into adjacent formations where it dolomitizes carbonates (Machel, 2004). This type of dolomitization is proposed as a source of dolomite cement in the thin sections because the dolomite cement is thought to be more regional than local and there is an underlying shale member directly beneath the middle member.

Thermochemical sulfate reduction is an inorganically produced redox-reaction where sulfate is reduced by hydrocarbons at temperatures of about 100-140°C or up to 160-180°C in some settings (Machel, 2001). This reduction is proposed as a source of the late stage calcite cement and pyrite seen in thin sections (see reactions below).

$$SO_4^{2-} + 2CH_2O => H_2S + 2HCO_3^-$$
$$CaSO_4 + 2CH_2O => H_2S + CaCO_3 + CO_2 + H_2O$$

The first reaction is a more general form of sulfate reduction where sulfate and organic matter produce hydrogen sulfide and bicarbonate. The second equation is a more specific form of sulfate reduction where anhydrite and organic material react to form hydrogen sulfide, calcium carbonate, carbon dioxide, and water. The bicarbonate or calcium carbonate from the two reactions could have produced the late stage calcite cement. Hydrogen sulfide from the two reactions could have reacted with iron to form the late stage pyrite (FeS_2).

Oil emplacement is one of the youngest events affecting diagenesis, so the dissolution of cement seen in thin sections may be related to organic acids. Organic acids are released during hydrocarbon maturation and expulsion, and can dissolve carbonate cement (Barth and Bjørlykke, 1993; Pitman et al., 2001).

5.4. Subsurface Mapping

A 100 foot Prairie Formation local thin in the middle of Divide County is partially filled in by an extra 18 feet of lower shale, 15 ft of facies B (bioturbated siltstone), and 9 ft of facies G (parallel laminated sandstone). Prairie dissolution appears to have ceased during deposition of units above facies G in the upper portion of the middle member and in the upper shale member. Prairie Formation dissolution creating thicks in overlying formations has been discussed by other authors such as Parker (1967), Smith and Pullen (1967), and LeFever and LeFever (2005). Middle member unit thicknesses from the lower shale member up to unit MB 6 follow the general trends of the lower shale and middle member in showing an increase in thickness from the southwest corner to the northeast corner of the study area. This trend indicates a northwest-southeast oriented shoreline somewhere southwest of the study area. Units MB 7 to MB 10 do not show enough thickness trends to infer shoreline location.

The middle member isopach compared to the upper shale member isopach shows a general shift in sediment thickness to the west side and south side of the study area. Most units in the middle member have an additional thickness trend from the southeast corner to northeast and slightly west corner of the study area, which indicates that the area of the thickness trend was a paleogeographic low compared to the surrounding area during much of its deposition.

Core description to log tie-ins for the Torgeson 2-15HS, Tomlinson 3-1HN, and five test wells confirmed the homogeneity of facies from the upper Bakken shale to clean sand (facies G) and confirmed the heterogeneity of facies below the clean sand. The heterogeneous facies below the clean sand are similar in lithology, but vary back and forth too much to be correlated across the study area.

6. Conclusion

The Torgeson 2-15HS and Tomlinson 3-1HN wells only have slight variations in grain mineralogy, shape, and angularity which indicates similar depositional environments and sediment sources. Provenance plots indicate that middle member grains come from a stable craton interior continental block provenance. Data from these two wells were not sufficient to determine the source, distribution, or depositional environment of the study area.

Similar dolomite cement compositions across the Torgeson 2-15HS and Tomlinson 3-1HN wells indicate similar fluids and diagenesis between the two wells. Similarity of cements between the two wells in this study and throughout the Williston Basin (Pitman et al., 2001) indicate that diagenesis was more regional than local. Preliminary SEM results show that the types of cements and their relative relationships to each other are (oldest to youngest):

1. Syntaxial quartz overgrowth
2. Feldspar alteration to clay
3. Partial dissolution of quartz and feldspar/clay
4. Dolomite cement
5. Partial dissolution of dolomite cement
6. Calcite cement
7. Partial dissolution of dolomite and calcite cement
8. Precipitation of pyrite

Chemical compaction is thought to have formed syntaxial quartz overgrowth. Burial dolomitization is proposed as the source of dolomite cement. Thermochemical sulfate reduction is proposed as the source of later stage calcite and pyrite. Partial dissolution of carbonate cement may have been related to organic acids from hydrocarbon maturation and expulsion.

The Prairie Formation evaporite underwent local and regional dissolution during the lower shale and middle member deposition of the Bakken Formation. Sandstone facies D, E, and F are thought to have been protected from erosion in areas of Prairie Formation dissolution during deposition. Facies from the top of the middle member of the Bakken Formation to the clean sand (facies G) are fairly correlative across the study area and facies below the clean sand are heterogeneous and difficult to correlate across the study area. There was a northwest-southeast oriented shoreline somewhere southwest of the study area during lower shale and middle member deposition. A major change in shoreline to an unknown location happened sometime between middle member and upper shale deposition.

7. Future Work

Thin section analysis and SEM work for the Torgeson 2-15HS and Tomlinson 3-1HN wells alone does not provide enough information to infer sediment source, distribution, or deposition in the study area. Analysis of additional thin sections across Divide County would provide insight on sedimentation of the middle member of the Bakken Formation.

Cementation within the middle member of the Bakken Formation is heterogeneous (Figure 63). Pitman et al. (2001) suggested that organic acids released during hydrocarbon maturation and expulsion into the middle member could dissolve carbonate cement. Detailed work on complete diagenesis of the middle member is needed to explore the idea of organic acids dissolving carbonate cement and whether or not this possible dissolution had an impact on cement heterogeneity. In addition, stable isotope work would help determine the order of diagenetic events and the processes they were formed by.

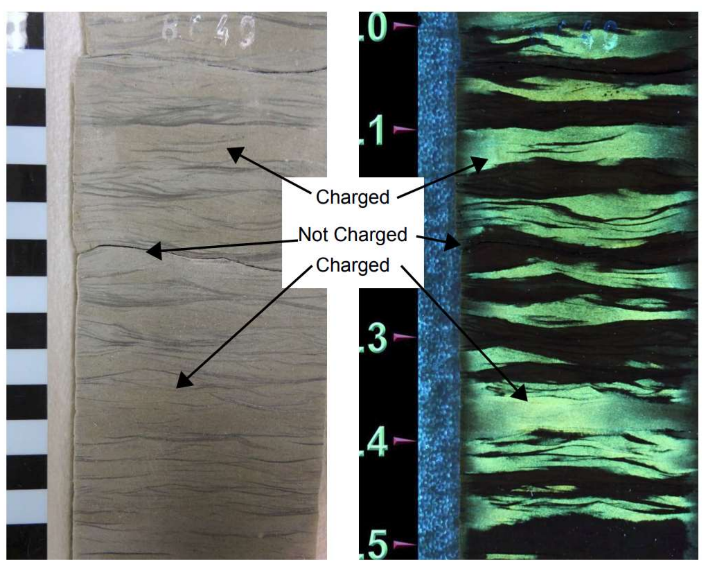


Figure 63. Patchy oil staining in Tomlinson 3-1HS facies E at 8649 ft core depth (from Hofmann et al., 2014). Left image taken with normal light. Right image taken with UV light, where oil displays a bright fluorescence.

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9. Appendix A: Point Count Data for Mineralogy

			Measured Depth (ft)		GRAINS								INTERSTITIAL					
					Quartz		Feldspar							Matrix		Cement		
Well	Slide	Facies	Core	Log	Mono-crystalline	Poly-crystalline	Alkali	Plagioclase	Calcite	Opaque	Other	Bioclastic Silica	Void	Clay	Micrite (calcite & dolomite)	Calcite	Dolomite	Quartz
Torgeson 2-15HS	3	A	7894.07	7894.07	24	1	0	0	1	11	1	0	1	26	65	4	170	0
	4		7896.00	7896.00	34	0	0	0	0	34	0	0	5	11	N/A	36	210	0
	5	H	7900.15	7900.15	31	0	0	2	0	22	0	0	2	37	164	0	75	0
	6		7904.04	7904.04	42	0	0	0	0	24	0	0	2	18	99	8	130	0
	7		7906.30	7906.30	74	1	0	1	8	45	0	0	3	6	47	77	146	0
	8	C	7908.70	7908.70	85	0	0	1	0	32	1	0	13	6	14	2	171	0
	9		7910.00	7910.00	91	0	0	1	0	26	1	0	18	27	42	0	131	0
	10	G	7912.00	7912.00	337	1	3	3	0	29	0	0	180	15	N/A	3	311	0
	11		7913.70	7913.70	142	0	0	2	3	6	0	0	56	18	39	34	75	0
	12		7917.25	7917.25	132	0	0	0	0	4	3	0	43	49	0	57	56	0
	13	C	7921.78	7921.78	114	0	0	1	0	7	1	0	46	10	10	0	140	0
	14		7925.50	7925.50	129	5	0	0	0	10	1	0	73	34	54	0	143	0
	15	B	7929.50	7929.50	97	0	0	0	0	1	1	0	52	22	41	0	113	0
	16		7935.37	7935.37	80	0	0	2	0	4	1	0	3	25	62	8	130	0
	17		7941.50	7941.50	100	0	0	0	0	7	2	1	33	34	29	1	145	0
	18		7945.60	7945.60	92	0	0	1	0	6	2	0	60	26	41	0	117	0
	19		7950.00	7950.00	46	0	0	0	2	3	2	0	10	29	78	70	85	0
	20	A	7953.50	7953.50	12	0	0	0	5	5	0	0	3	18	130	112	46	0

			Measured Depth (ft)		GRAINS							INTERSTITIAL							
					Quartz		Feldspar						Matrix		Cement				
Well	Slide	Facies	Core	Log	Mono-crystalline	Poly-crystalline	Alkali	Plagioclase	Calcite	Opaque	Other	Void	Clay	Micrite (calcite & dolomite)	Calcite	Dolomite	Anhydrite/ Fluorapatite	Quartz	Silica
Tomlinson 3-1HN	2	H	8630.15	8638.15	13	0	0	1	0	13	1	2	20	245	0	39	0	0	0
	3		8635.11	8643.11	67	0	0	0	0	21	0	3	25	122	0	112	0	0	0
	4	C	8637.12	8645.12	78	0	0	1	0	12	13	8	22	95	20	68	0	0	0
	5	G	8641.15	8649.15	153	0	0	0	0	7	9	42	12	33	66	33	0	0	0
	6	F	8643.5	8651.50	117	1	0	1	0	9	0	9	27	39	19	58	51	0	0
	7	E	8646.17	8654.17	126	0	0	0	0	10	0	11	18	52	4	61	20	0	0
	8		8648.8	8656.80	104	1	0	1	0	10	1	2	20	28	28	109	19	0	0
	9		8652.13	8660.13	85	0	0	0	0	11	6	55	13	46	5	111	16	0	0
	10	D	8655.12	8663.12	125	0	0	1	0	22	5	6	19	28	29	86	3	0	0
	11	C	8661.12	8669.12	100	0	0	0	0	17	4	25	40	38	6	89	7	0	0
	12	B	8669.2	8677.20	86	0	0	2	0	11	2	22	19	21	45	105	5	0	0
	13		8674.55	8682.55	88	0	0	0	0	21	0	14	28	8	21	127	8	0	0
	14		8683.14	8691.14	86	0	0	1	1	13	0	22	21	21	71	117	9	0	0
	15		8688.14	8696.14	64	0	0	0	10	12	0	31	21	49	98	65	17	0	0

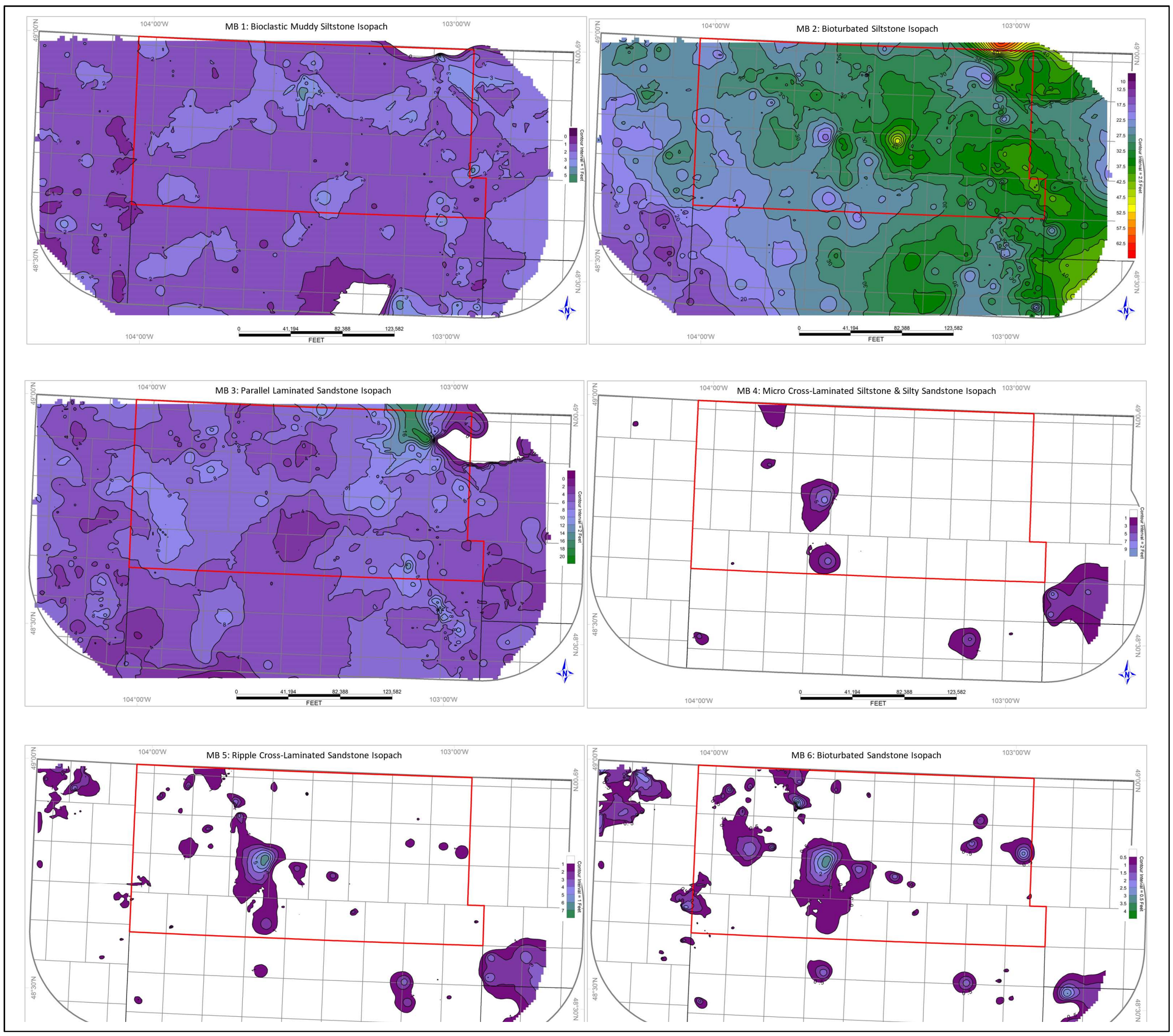
10. Appendix B: Point Count Data for Grain Size & Angularity

					GRAIN SIZE(mm)						GRAIN ANGULARITY					
					Sand					Silt/Clay						
			Measured Depth (ft)		v. Coarse	Coarse	Medium	Fine	v. Fine	<0.0625	Well Rounded	Rounded	Sub-Rounded	Sub-Angular	Angular	Very Angular
Well	Slide	Facies	Core	Log	1-2	0.5-1	0.25-0.5	0.125-0.25	0.0625-0.12							
Torgeson 2-15HS	3	A	7894.07	7894.07	0	0	0	0	13	95	1	19	31	20	24	14
	4		7896.00	7896.00	0	0	0	0	16	84	1	20	22	25	27	5
	5	H	7900.15	7900.15	0	0	0	0	9	91	0	12	37	29	13	9
	6		7904.04	7904.04	0	0	0	0	19	82	0	8	30	34	21	8
	7		7906.30	7906.30	0	0	0	5	28	67	1	10	29	37	20	3
	8	C	7908.70	7908.70	0	0	0	1	30	69	0	14	48	28	13	1
	9		7910.00	7910.00	0	0	0	1	31	68	0	11	52	30	7	1
	10	G	7912.00	7912.00	0	0	0	26	56	18	2	8	35	39	14	2
	11		7913.70	7913.70	0	0	0	29	56	15	0	6	43	40	10	2
	12		7917.25	7917.25	0	0	0	36	51	13	2	6	47	38	7	0
	13	C	7921.78	7921.78	0	0	0	1	33	66	1	4	47	41	7	0
	14		7925.50	7925.50	0	0	0	0	16	84	1	4	40	47	7	1
	15	B	7929.50	7929.50	0	0	0	0	14	86	0	0	42	50	10	0
	16		7935.37	7935.37	0	0	0	0	7	93	0	2	43	46	8	2
	17		7941.50	7941.50	0	0	0	0	9	91	0	3	34	55	6	2
	18		7945.60	7945.60	0	0	0	0	6	94	1	1	39	51	8	0
	19		7950.00	7950.00	0	0	0	0	2	98	0	1	33	45	20	1
	20	A	7953.50	7953.50	0	0	0	0	2	98	0	1	38	56	5	0

					GRAIN SIZE(mm)						GRAIN ANGULARITY					
					Sand					Silt/Clay						
			Measured Depth (ft)		v. Coarse	Coarse	Medium	Fine	v. Fine	<0.0625	Well Rounded	Rounded	Sub-Rounded	Sub-Angular	Angular	Very Angular
Well	Slide	Facies	Core	Log	1-2	0.5-1	0.25-0.5	0.125-0.25	0.0625-0.12							
Tomlinson 3-1 HN	2	H	8630.15	8638.15	0	0	0	0	1	99	0	2	50	44	4	0
	3		8635.11	8643.11	0	0	0	0	10	90	0	4	47	39	9	1
	4	C	8637.12	8645.12	0	0	0	0	19	81	0	7	48	38	3	4
	5	G	8641.15	8649.15	0	0	0	35	48	17	1	6	41	36	15	1
	6	F	8643.50	8651.50	0	0	0	7	43	57	0	4	40	59	3	1
	7	E	8646.17	8654.17	0	0	0	3	28	69	0	1	29	60	9	1
	8		8648.80	8656.80	0	0	0	2	20	79	1	1	33	49	15	3
	9		8652.13	8660.13	0	0	0	0	36	64	1	5	43	40	9	2
	10	D	8655.12	8663.12	0	0	0	2	33	65	2	2	49	37	11	0
	11	C	8661.12	8669.12	0	0	0	2	22	76	0	2	45	46	5	2
	12	B	8669.20	8677.20	0	0	0	0	19	81	0	4	45	40	11	0
	13		8674.55	8682.55	0	0	0	0	14	86	0	1	45	46	8	0
	14		8683.14	8691.14	0	0	0	0	8	92	0	2	58	33	6	1
	15		8688.14	8696.14	0	0	0	0	6	94	0	1	49	46	4	0

11. Appendix C: Isopach Maps for Units MB 1 to MB 6

Unit tops MB 1 through MB 6, located below MB 7 (facies G), were lumped together and presented as one isopach unit for this thesis due to the units' variability and difficultly to correlate. I have included individual isopach maps of units MB 1 to MB 6 in this appendix for the sake of thoroughness. In the maps, Divide County is outlined in red, other county lines are black, and township lines are gray.



12. Appendix D: Unit Tops for all Wells Used in This Study

Tables showing the measured depth in feet of each unit top used in this study. Bakken to Three Forks tops were correlated by me. The first table shows unit top descriptions, the second table shows US wells, and the third table shows Canadian wells. Twenty-three wells in the US lacked sufficient well logs to correlate. The datum column label was shortened to "Datm" and its values were rounded to the nearest integer in the US wells table to make it fit in the document.

Top Name	Top Description
BKKN	Bakken Formation
MB10	Middle member of the Bakken Formation; Facies A: Bioclastic Muddy Siltstone
MB_9	Middle member of the Bakken Formation; Facies H: Bioturbated Interbedded Sandstone and Mudstone-Sandstone/Mudstone-and-Sandstone
MB_8	Middle member of the Bakken Formation; Facies C: Parallel Laminated Silty Sandstone
MB_7	Middle member of the Bakken Formation; Facies G: Parallel Laminated Sandstone
MB_6	Middle member of the Bakken Formation; Facies F: Bioturbated Sandstone
MB_5	Middle member of the Bakken Formation; Facies E: Ripple Cross-Laminated Sandstone
MB_4	Middle member of the Bakken Formation; Facies D: Micro Cross-Laminated Siltstone and Silty Sandstone
MB_3	Middle member of the Bakken Formation; Facies C: Parallel Laminated Silty Sandstone
MB_2	Middle member of the Bakken Formation; Facies B: Bioturbated Siltstone
MB_1	Middle member of the Bakken Formation; Facies A: Bioclastic Muddy Siltstone
L_SH	Lower shale member of the Bakken Formation
TRFK	Three Forks Formation
PRVP	Prairie Formation (Prairie evaporite)
WPGS	Winnipegosis Formation

USA Wells															
UWI/API	Datm	BKKN	MB10	MB_9	MB_8	MB_7	MB_6	MB_5	MB_4	MB_3	MB_2	MB_1	L_SH	TRFK	PRVP	WPGS
33013001890000	2389														10458	10960
33013007220000	2439	8847	8857	8857	8861	8868	8883	8883	8883	8883	8888	8925	8929	8965	10221	10690
33013007490000	2459	8853	8864	8866	8874	8878	8890	8890	8890	8890	8895	8930	8935	8970	10222	10712
33013008010000	2404	8566	8580	8581	8588	8597	8604	8604	8604	8604	8613	8646	8647	8678	9966	10532
33013008290000	1921	7365	7376	7378	7392	7396	7399	7399	7399	7399	7404	7439	7441	7467	8775	9350
33013008770000	1941	7364	7376	7377	7390	7395	7398	7398	7398	7398	7401	7432	7435	7461		
33013010310000	2317	9289	9302	9302	9307	9312	9316	9316	9321	9327	9330	9363	9365	9401		
33013011700000	2329	9146	9160	9161	9168	9173	9179	9179	9183	9191	9196	9221	9224	9256	10493	10910
33013011720000	2415	9117	9130	9132	9141	9148	9155	9155	9155	9155	9159	9188	9190	9222	10450	10887
33013011740000	2392	9068	9082	9083	9097	9100	9105	9105	9105	9105	9108	9147	9150	9183	10460	10970
33013011880000	2387	9063	9076	9077	9081	9088	9100	9100	9100	9100	9106	9148	9149	9185	10492	11070
33013011900000	2421	9139	9151	9152	9156	9161	9175	9175	9175	9175	9179	9217	9218	9249	10475	10900
33013011930000	2418	9133	9145	9147	9150	9156	9169	9169	9169	9169	9172	9210	9213	9247	10500	10976
33013011980000	2138	8066	8081	8083	8088	8093	8106	8106	8106	8106	8111	8137	8139	8167	9454	10048
33013012070000	2447	8646	8663	8664	8673	8681	8685	8685	8685	8685	8693	8718	8719	8753	10052	10677
33013012200000	2470	8801	8817	8818	8825	8833	8839	8839	8839	8839	8847	8873	8875	8909	10211	10845
33013012560000	2387	8977	8993	8994	9009	9011	9021	9021	9021	9021	9024	9056	9058	9094	10403	10963
33013013130000	2111	8056	8070	8071	8075	8080	8092	8092	8092	8092	8097	8128	8130	8157	9447	10000
33013013150000	2457	8806	8820	8822	8833	8839	8847	8847	8847	8847	8852	8889	8890	8922	10206	10722
33013013160000	2089	8047	8061	8063	8071	8080	8083	8083	8083	8083	8090	8119	8120	8149	9442	10005
33023000030000	2242	9011	9025	9027	9029	9032	9037	9039	9043	9043	9046	9071	9074	9102	10302	10646
33023000080000	1949														9213	9643
33023000100000	2261														9732	10035
33023000240000	2206	7742	7752	7754	7763	7766	7772	7772	7772	7772	7779	7798	7801	7828	9100	9408
33023000750000	2104	8454	8468	8470	8479	8481	8484	8486	8492	8492	8496	8522	8524	8546		
33023000810000	2345	9222	9232	9232	9237	9241	9250	9250	9250	9250	9256	9285	9286	9306		
33023000920000	2136	8077	8090	8091	8099	8108	8118	8119	8121	8121	8126	8148	8150	8179		
33023001000000	2157	8744	8758	8759	8768	8776	8779	8779	8779	8779	8783	8820	8821	8851		
33023001030000	2249	8453	8464	8466	8477	8482	8490	8490	8490	8490	8496	8525	8528	8552	9760	10074
33023001090000	2214	7977	7989	7991	8001	8005	8008	8008	8008	8008	8018	8046	8047	8072		
33023001150000	2321	8524	8537	8538	8544	8548	8559	8559	8559	8559	8566	8597	8599	8623	9820	10132
33023001160000	2112	8855	8868	8869	8876	8881	8884	8885	8886	8886	8890	8922	8923	8946	10146	10455
33023001190000	2290	9100	9111	9113	9123	9129	9133	9133	9133	9133	9138	9173	9175	9206	10444	10806
33023001230000	2291	8664	8674	8676	8683	8692	8695	8695	8695	8695	8705	8735	8738	8762	10025	10390
33023001240000	2373	8834	8846	8848	8856	8863	8872	8872	8872	8872	8876	8915	8918	8953	10195	10647
33023001250000	2364	8468	8478	8479	8485	8489	8503	8503	8503	8503	8512	8544	8546	8574	9805	10211
33023001260000	2243	8985	8997	8998	9002	9006	9013	9013	9013	9013	9022	9050	9053	9076	10270	10608

UWI/API	Datm	BKKN	MB10	MB_9	MB_8	MB_7	MB_6	MB_5	MB_4	MB_3	MB_2	MB_1	L_SH	TRFK	PRVP	WPGS
33023001270000	2209	8047	8058	8059	8069	8074	8079	8079	8079	8079	8083	8111	8115	8140	9393	9744
33023001300000	2300	8987	8999	9000	9007	9015	9021	9021	9021	9021	9025	9059	9063	9092	10363	10764
33023001430000	1903	7345	7355	7356	7364	7368	7387	7387	7387	7387	7394	7431	7436	7472	8764	9175
33023001500000	2145	8192	8205	8207	8217	8222	8229	8229	8229	8229	8238	8260	8261	8283	9478	9784
33023001520000	2349	8418	8428	8430	8437	8441	8449	8449	8449	8449	8455	8486	8488	8515	9736	10037
33023001560000	2295	9132	9143	9145	9154	9162	9170	9170	9170	9170	9176	9201	9205	9234	10417	10852
33023001570000	2201	8352	8361	8363	8371	8374	8381	8383	8385	8385	8393	8425	8427	8453	9630	9950
33023001580000	2100	8872	8885	8887	8894	8897	8901	8901	8901	8901	8911	8935	8937	8958	10158	10460
33023001610000	2101	8435	8448	8449	8460	8464	8472	8472	8472	8472	8479	8504	8506	8527	9704	9995
33023001630000	2244	8474	8485	8486	8498	8504	8508	8508	8508	8508	8514	8544	8547	8573	9763	10068
33023001670000	2141	8102	8112	8113	8120	8127	8133	8135	8137	8137	8142	8177	8181	8209	9490	9864
33023001680000	2104	8437	8449	8451	8463	8466	8469	8471	8472	8473	8481	8504	8506	8528	9713	10009
33023001700000	2075	8405	8417	8418	8430	8434	8438	8439	8441	8440	8445	8472	8473	8496	9674	9971
33023001710000	1918	7487	7497	7498	7506	7511	7523	7523	7523	7523	7530	7564	7566	7594	8866	9376
33023001720000	2236	9161	9172	9173	9183	9186	9189	9189	9189	9189	9195	9220	9224	9242	10455	10797
33023001740000	2403	8681	8694	8696	8708	8712	8715	8715	8715	8715	8722	8761	8763	8795	10065	10594
33023001770000	1944	7647	7657	7659	7668	7672	7682	7682	7682	7682	7694	7722	7723	7748	9030	9414
33023001780000	2171	8193	8203	8204	8214	8218	8224	8224	8224	8224	8234	8262	8264	8290	9465	9789
33023001790000	2472	8865	8877	8877	8882	8889	8898	8900	8901	8901	8906	8948	8949	8985	10246	10717
33023001810000	2349	9273	9284	9285	9291	9298	9301	9301	9301	9301	9306	9336	9337	9357	10583	10930
33023001840000	2180	8197	8208	8210	8220	8225	8230	8230	8230	8230	8242	8268	8270	8296	9486	9820
33023001870000	2101	8909	8921	8923	8928		8941	8941	8941	8940	8947	8971	8972	8992	10195	10500
33023001880000	2159	7962	7973	7974	7983	7989	7994	7993	7993	7993	8000	8031	8032	8055	9324	9676
33023001890000	2167	8214	8224	8225	8235	8239	8243	8243	8243	8243	8253	8281	8283	8310	9476	9797
33023001910000	2268	8622	8632	8633	8644	8649	8653	8653	8653	8653	8659	8691	8693	8719	9913	10247
33023001920000	2107	8451	8462	8465	8477	8480	8484	8484	8484	8484	8489	8517	8518	8541	9714	10006
33023001930000	2463	8867	8879	8880	8889	8892	8905	8905	8905	8905	8912	8953	8955	8990	10255	10720
33023001940000	2292	8043	8055	8056	8065	8069	8074	8074	8074	8074	8083	8110	8112	8135	9367	9702
33023001950000	2117	8624	8636	8637	8644	8647	8658	8658	8658	8658	8662	8687	8688	8707	9896	10222
33023001960000	2167	8950	8963	8965	8975	8979	8982	8982	8982	8982	8989	9013	9015	9038	10243	10547
33023001990000	2255	8168	8178	8179	8189	8193	8202	8203	8203	8202	8207	8238	8241	8265	9509	9853
33023002020000	2108	8943	8956	8957	8967	8977	8977	8977	8977	8977	8979	9005	9007	9027	10223	10543
33023002030000	2131	8550	8560	8561	8573	8577	8579	8580	8583	8583	8588	8616	8617	8640	9844	10161
33023002050000	2104	8532	8541	8544	8549	8554	8570	8570	8570	8570	8578	8628	8630	8675	9966	10190
33023002080000	1901	7353	7364	7365	7373	7378	7398	7398	7398	7398	7406	7448	7449	7490		
33023002090000	2203	8050	8059	8060	8071	8076	8080	8080	8080	8080	8085	8114	8117	8140		
33023002100000	2260	8021	8034	8035	8047	8049	8053	8053	8053	8053	8065	8091	8092	8116	9374	9702
33023002110000	2072	7855	7865	7867	7877	7883	7887	7887	7887	7887	7892	7927	7928	7953	9200	9538
33023002130000	2290	8316	8327	8328	8336	8344	8348	8348	8348	8348	8355	8391	8393	8419	9675	10091
33023002160000	2185	7859	7866	7868	7876	7879	7881	7883	7886	7886	7892	7918	7920	7942	9213	9517
33023002170000	2079	7881	7893	7894	7904	7911	7914	7914	7914	7914	7921	7954	7955	7979	9226	9572
33023002190000	2338	8285	8294	8296	8306	8311	8315	8315	8315	8315	8319	8354	8356	8382	9610	9932
33023002200000	2204	7933	7944	7946	7957	7961	7964	7963	7963	7964	7967	7999	8001	8024	9263	9590
33023002210000	1983	7680	7689	7690	7699	7704	7711	7711	7711	7711	7717	7748	7750	7774	9048	9413
33023002220000	2044	7807	7819	7820	7830	7834	7842	7842	7842	7842	7849	7880	7881	7908	9171	9534
33023002230000	2127	7924	7935	7936	7945	7950	7958	7958	7958	7958	7963	7998	7999	8023	9267	9618
33023002270000	2141	7808	7818	7820	7832	7835	7838	7838	7838	7838	7842	7869	7871	7893	9166	9471
33023002290000	2266	8997	9007	9008	9019	9023	9029	9030	9030	9029	9035	9069	9071	9098	10335	
33023002310000	2180	8006	8016	8017	8028	8044	8044	8044	8044	8044	8050	8071	8072	8095	9354	9696
33023002320000	1992	7581	7592	7593	7605	7609	7612	7612	7612	7612	7624	7648	7649	7674	8954	9315
33023002330000	1935	7487	7496	7497	7503	7509	7520	7520	7520	7520	7526	7557	7558	7581	8867	9254
33023002340000	1938	7485	7493	7495	7504	7509	7519	7519	7519	7519	7525	7556	7557	7580	8898	9272
33023002370000	2184	8053	8067	8068	8079	8083	8086	8085	8085	8086	8091	8122	8123	8148	9366	9690
33023002380000	2109	8457	8468	8469	8483	8486	8489	8489	8489	8489	8498	8522	8523	8546	9723	10016
33023002390000	2150	7967	7978	7979	7989	8002	8002	8002	8002	8002	8008	8032	8033	8056	9321	9670
33023002400000	1914	7461	7470	7471	7478	7483	7493	7493	7493	7493	7502	7533	7534	7558	8848	9238
33023002420000	2080	8435	8451	8453	8463	8468	8473	8473	8473	8473	8483	8504	8505	8527	9720	10018
33023002430000	2174	8822	8832	8832	8837	8841	8852	8852	8852	8852	8859	8889	8892	8914	10111	10473
33023002440000	2348	8914	8924	8925	8931	8941	8949	8949	8949	8949	8953	8991	8992	9021		
33023002460000	2167	7983	7992	7993	8003	8009	8012	8012	8012	8012	8018	8048	8050	8072	9322	9670
33023002510000	2110	7904	7915	7915	7921	7928	7937	7938	7937	7938	7944	7976	7977	8001		
33023002520000	2151	7967	7977	7978	7987	7992	7999	7999	7999	7999	8006	8037	8037	8062	9312	9657
33023002530000	2065	7697	7707	7708	7712	7717	7729	7729	7729	7729	7734	7767	7768	7793	9101	9440
33023002540000	2154	7968	7977	7978	7988	7994	7999	7999	7999	7999	8005	8035	8037	8060		
33023002550000	2113	8447	8460	8461	8473	8476	8479	8479	8479	8479	8486	8514	8515	8538	9730	10030
33023002560000	2243	8079	8090	8091	8103	8107	8109	8109	8109	8109	8111	8144	8145	8169	9394	9716
33023002570000	2302	9143	9153	9153	9156	9160	9169	9169	9169	9169	9176	9205	9207	9228	10455	10785
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33023002590000	2311	8698	8710	8711	8722	8727	8729	8729	8729	8729	8735	8770	8771	8794	10006	10312
33023002600000	2392	8958	8968	8970	8977	8984	8991	8991	8991	8991	8997	9031	9032	9057	10276	10626
33023002610000	2125	7922	7931	7933	7944	7948	7952	7952	7952	7952	7956	7985	7987	8009	9251	9566
33023002630000	2234	8086	8097	8098	8107	8113	8117	8117	8117	8117	8121	8153	8155	8178		
33023002640000	2404	8934	8945	8946	8956	8962	8967	8967	8967	8967	8973	9008	9010	9035		
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33023002660000	2145	7856	7865	7867	7878	7881	7885	7885	7885	7885	7892	7921	7922	7946	9196	9520
33023002680000	1925	7425	7434	7435	7444	7451	7458	7458	7458	7458	7469	7497	7498	7524	8823	9217
33023002690000	2197	8688	8699	8701	8711	8716	8722	8722	8722	8722	8728	8758	8759	8785	9965	10265
33023002700000	2243	8958	8968	8969	8973	8977	8987	8987	8987	8987	8993	9027	9028	9054	10254	10603
33023002710000	2164	8300	8316	8318	8327	8331	8338	8340	8342	8342	8346	8373	8375	8398	9595	9896
33023002720000	2117	7906	7915	7917	7928	7932	7934	7934	7934	7934	7938	7968	7969	7992	9245	9551
33023002730000	2292	8653	8664	8665	8674	8677	8681	8681	8682	8682	8689	8726	8727	8751		

UWI/API	Datm	BKKN	MB10	MB_9	MB_8	MB_7	MB_6	MB_5	MB_4	MB_3	MB_2	MB_1	L_SH	TRFK	PRVP	WPGS
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33023002750000	2148	7932	7942	7944	7953	7958	7963	7963	7962	7963	7967	7997	7998	8021	9259	9569
33023002760000	2280	9278	9289	9291	9302	9306	9310	9310	9310	9310	9317	9352	9353	9383	10664	11052
33023002770000	2382	8079	8090	8092	8103	8107	8110	8111	8113	8116	8122	8147	8149	8173		
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33023002800000	2238	7711	7718	7720	7730	7735	7739	7739	7739	7739	7744	7772	7774	7796	9081	9398
33023002810000	2156	7963	7974	7975	7984	7988	7996	7996	7996	7996	8002	8034	8036	8060		
33023002820000	2141	7881	7890	7891	7901	7904	7907	7909	7909	7909	7913	7945	7946	7969	9212	9530
33023002840000	2082	8707	8717	8719	8729	8732	8735	8734	8734	8735	8738	8770	8771	8792	10001	10332
33023002850000	2222	8103	8116	8116	8126	8130	8135	8135	8135	8135	8141	8173	8175	8199	9434	9769
33023002860000	2144	7930	7938	7939	7945	7951	7962	7962	7962	7962	7967	8000	8001	8028		
33023002870000	2109	7857	7866	7868	7877	7883	7889	7889	7889	7889	7894	7924	7926	7953	9221	9570
33023002910000	2102	7861	7871	7873	7883	7887	7892	7892	7892	7892	7896	7926	7928	7950	9203	9504
33023002920000	2134	7843	7851	7854	7866	7868	7872	7872	7872	7872	7880	7904	7906	7928	9176	9494
33023002930000	2203	7815	7823	7825	7835	7838	7841	7844	7845	7845	7851	7876	7877	7899	9177	9481
33023002940000	2229	8125	8139	8141	8151	8155	8157	8158	8158	8158	8163	8194	8196	8221	9438	9764
33023002960000	1929	7613	7623	7624	7633	7638	7646	7646	7646	7646	7655	7686	7687	7711	8971	9428
33023002970000	2194	7827	7840	7842	7854	7859	7864	7866	7867	7867	7870	7897	7899	7925	9181	9501
33023002980000	2260	8090	8102	8103	8112	8116	8120	8124	8127	8127	8132	8157	8158	8182	9427	9747
33023002990000	2120	7954	7964	7966	7976	7981	7983	7985	7987	7987	7990	8019	8021	8045	9276	9594
33023003030000	2352	9148	9158	9159	9171	9175	9178	9178	9178	9178	9186	9213	9215	9237	10437	10655
33023003040000	2222	8100	8113	8114	8122	8128	8132	8131	8131	8131	8141	8170	8171	8195		
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33023003070000	2219	8043	8055	8057	8069		8076	8076	8076	8076	8080	8113	8114	8138	9381	9706
33023003080000	2222	8132	8144	8146	8157	8163	8168	8168	8168	8168	8173	8202	8204	8230	9468	9786
33023003090000	2072	7963	7972	7974	7978	7986	7998	7998	7998	7998	8002	8037	8039	8067	9316	9795
33023003100000	2028	7883	7894	7894	7899	7907	7918	7918	7918	7917	7929	7955	7956	7980	9234	9701
33023003110000	2199	8352	8365	8367	8377	8380	8386	8388	8390	8390	8398	8423	8425	8449	9652	9970
33023003120000	2091	7882	7892	7893	7903	7911	7914	7915	7919	7919	7924	7950	7953	7978		
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33023003140000	2079	7841	7850	7852	7856	7861	7874	7874	7874	7874	7879	7912	7915	7941	9190	9556
33023003150000	2227	8652	8663	8664	8671	8675	8682	8683	8683	8682	8686	8722	8724	8746		
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33023003220000	1909	7407	7416	7417	7427	7432	7441	7441	7441	7441	7449	7483	7484	7513	8777	9263
33023003240000	2304	8015	8027	8028	8038	8043	8046	8046	8046	8046	8053	8083	8086	8111	9374	9682
33023003250000	2301	8183	8194	8196	8205	8209	8215	8215	8215	8215	8223	8253	8254	8278	9513	9879
33023003260000	2128	7873	7884	7886	7896	7900	7907	7907	7907	7907	7912	7940	7942	7969	9230	9580
33023003270000	2243	8074	8084	8086	8096	8101	8103	8107	8111	8111	8114	8139	8141	8165	9418	9740
33023003320000	2272	8138	8152	8153	8162	8166	8170	8170	8170	8170	8175	8209	8211	8235	9480	9794
33023003330000	2224	8056	8068	8069	8079	8084	8087	8087	8087	8087	8097	8125	8126	8150		
33023003340000	2079	8610	8622	8624	8637	8640	8642	8643	8644	8644	8648	8687	8688	8717	9966	10324
33023003350000	2211	8069	8079	8080	8086	8091	8102	8102	8102	8102	8108	8136	8137	8159		
33023003360000	1902	7388	7396	7398	7407	7411	7423	7424	7424	7423	7434	7465	7467	7495		
33023003380000	2272	9147	9157	9159	9166	9172	9183	9183	9183	9183	9190	9221	9223	9250	10498	10850
33023003390000	2260	8085	8097	8098	8109	8113	8115	8115	8115	8115	8119	8153	8154	8179		
33023003400000	2006	7944	7955	7956	7967	7973	7976	7976	7976	7976	7983	8017	8019	8044	9323	9690
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33023003420000	2102	8570	8582	8583	8589	8597	8604	8604	8604	8604	8614	8646	8647	8675	9934	10310
33023003430000	2078	7842	7851	7853	7862	7868	7873	7873	7873	7873	7878	7910	7914	7941		
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33023003490000	2206	8079	8092	8093	8104	8109	8111	8111	8112	8111	8115	8148	8149	8172		
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33023003550000	2320	8366	8379	8381	8392	8396	8400	8400	8400	8400	8403	8435	8438	8464	9706	10060
33023003560000	2297	8619	8627	8629	8638	8642	8649	8652	8659	8667	8677	8695	8696	8722		
33023003570000	2166	7803	7814	7816	7825	7832	7840	7840	7840	7840	7845	7873	7876	7902		
33023003580000	2155	7974	7987	7988	7997	8002	8008	8008	8008	8008	8016	8044	8047	8074		
33023003590000	2314	9099	9110	9113	9120	9126	9130	9130	9130	9130	9136	9172	9174	9202	10440	10820
33023003600000	2184	8025	8035	8037	8044	8048	8060	8060	8060	8060	8066	8097	8098	8124		
33023003630000	1924	7665	7676	7677	7688	7692	7697	7699	7700	7700	7709	7738	7739	7764	9020	9488
33023003640000	2332	8734	8743	8745	8750	8755	8769	8769	8769	8769	8775	8813	8814	8840	10113	10475
33023003650000	2123	8754	8765	8766	8771	8774	8782	8782	8782	8782	8788	8821	8822	8845		
33023003670000	2309	8700	8711	8712	8721	8726	8734	8734	8734	8734	8740	8775	8777	8801	10053	10444
33023003680000	2327	8763	8772	8773	8777	8784	8797	8797	8797	8797	8801	8838	8840	8865	10124	
33023003690000	2327	8711	8722	8725	8734	8738	8746	8746	8746	8746	8754	8791	8792	8817	10118	10482
33023003700000	2295	8732	8743	8745	8753	8760	8764	8764	8764	8764	8768	8807	8809	8829	10091	10473
33023003710000	2350	8743	8754	8756	8765	8774	8777	8777	8777	8777	8781	8820	8822	8849		
33023003730000	2319	8718	8728	8729	8737	8745	8751	8751	8751	8751	8758	8793	8794	8819	10071	10450
33023003740000	2389	8585	8596	8598	8608	8612	8621	8621	8621	8621	8629	8667	8668	8697	9915	10367
33023003750000	2334	8806	8816	8819	8828	8833	8836	8836	8836	8836	8841	8878	8879	8907		
33023003770000	2324	8678	8689	8690	8695	8706	8710	8710	8710	8710	8717	8752	8754	8779	10032	10407
33023003780000	2243	8323	8334	8336	8342	8350	8355	8357	8359	8359	8370	8402	8405	8435	9735	10285
33023003790000	2335	8792	8802	8803	8810	8817	8827	8827	8826	8826	8830	8868	8869	8895		
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UWI/API	Datm	BKKN	MB10	MB_9	MB_8	MB_7	MB_6	MB_5	MB_4	MB_3	MB_2	MB_1	L_SH	TRFK	PRVP	WPGS
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33023003830000	2225	8378	8389	8391	8395	8404	8413	8413	8413	8413	8420	8450	8452	8476	9720	10064
33023003840000	1955	7714	7724	7726	7739	7742	7749	7749	7749	7749	7759	7785	7787	7811	9134	9588
33023003870000	1905	7353	7363	7364	7373	7376	7390	7390	7390	7390	7396	7430	7432	7460	8711	9176
33023003880000	2128	8754	8764	8765	8771	8776	8784	8784	8784	8784	8791	8824	8825	8849	10065	10404
33023003900000	2336	8465	8475	8477	8484	8491				8501	8509	8546	8547	8577	9830	10236
33023003920000	2348	8791	8801	8803	8809	8818	8823	8823	8823	8824	8829	8867	8868	8893	10152	
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33023003940000	2221	8321	8332	8333	8339	8345	8356	8356	8356	8356	8360	8391	8394	8420	9653	9990
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33023004040000	2111	8613	8625	8626	8638	8643	8648	8648	8648	8648	8651	8675	8676	8696	9891	10203
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33023004070000	2392	8927	8941	8942	8953	8959	8967	8967	8967	8967	8972	9006	9008	9040	10335	10885
33023004090000	2390	8893	8906	8908	8917	8924	8927	8927	8927	8927	8932	8975	8976	9009		
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33023004130000	2307	8870	8881	8882	8890	8891	8907	8907	8907	8907	8912	8947	8948	8976	10249	10686
33023004150000	2368	9019	9032	9033	9041	9048	9052	9052	9052	9052	9057	9090	9092	9120	10370	10805
33023004170000	2323	8823	8835	8836	8842	8850	8859	8859	8859	8859	8863	8903	8904	8932	10204	10670
33023004190000	2324	8834	8845	8847	8854	8863	8870	8870	8870	8870	8876	8905	8906	8933	10200	10567
33023004200000	2370	8828	8840	8842	8851	8857	8865	8865	8865	8865	8869	8911	8913	8945	10194	10659
33023004210000	2366	8996	9009	9010	9021	9025	9031	9031	9031	9031	9035	9075	9077	9108	10338	10771
33023004220000	2351	8596	8606	8607	8613	8618	8635	8635	8635	8635	8641	8682	8685	8716	9999	10398
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33023004260000	2258	8523	8535	8536	8548	8552	8557	8557	8557	8557	8565	8598	8600	8626	9880	10222
33023004290000	2386	8549	8558	8560	8564	8571	8585	8585	8585	8585	8594	8631	8632	8661		
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33023004330000	2010	7918	7925	7927	7937	7943	7949	7949	7949	7949	7957	7989	7991	8015	9276	9661
33023004390000	2118	8614	8625	8626	8640	8643	8645	8646	8647	8647	8650	8674	8675	8694	9877	10188
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33023004480000	2347	9249	9261	9261	9266	9270	9275	9274	9275	9274	9282	9311	9312	9332	10556	10908
33023004530000	2286	9274	9286	9287	9293	9297	9303	9303	9303	9303	9312	9339	9340	9362	10580	10951
33023004560000	2305	8674	8684	8686	8695	8699	8708	8708	8708	8708	8715	8751	8752	8776	10035	
33023004590000	2174	7830	7842	7843	7853	7858	7865	7865	7865	7865	7871	7897	7899	7924		
33023004600000	2118	7843	7855	7856	7865	7870	7875	7877	7879	7879	7883	7913	7914	7940		
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33023004710000	1932	7620	7629	7630	7637	7641	7653	7654	7654	7654	7659	7693	7694	7721	9010	9516
33023004810000	2174	7815	7825	7827	7836	7840	7842	7844	7848	7848	7853	7882	7883	7906	9156	9480
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33023004860000	2194	7870	7881	7884	7895	7900	7903	7903	7903	7903	7907	7937	7938	7963		
33023005100000	2202	7796	7806	7807	7817	7820	7826	7826	7826	7826	7831	7860	7862	7884	9164	9472
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33061003260000	2332	9617	9632	9634	9639	9643	9654	9654	9654	9654	9659	9697	9698	9742	10964	11346
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33105001610000	2450	9531	9544	9545	9551	9556	9562	9562	9562	9562	9566	9603	9604	9634		
33105002760000	2458	9505	9520	9520	9525	9528	9536	9536	9536	9537	9540	9574	9575	9602		
33105005490000	2446	9474	9485	9487	9492	9496	9505	9505	9505	9505	9513	9544	9547	9576	10754	11012
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33105006200000	2370	9384	9395	9397	9402	9407	9421	9421	9421	9421	9426	9455	9457	9486		
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33105006750000	2485	9595	9608	9610	9615	9620	9624	9625	9626	9626	9630	9665	9666	9698	10850	11198
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UWI/API	Datm	BKKN	MB10	MB_9	MB_8	MB_7	MB_6	MB_5	MB_4	MB_3	MB_2	MB_1	L_SH	TRFK	PRVP	WPGS
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33105006980000	2434	9642	9657	9658	9659	9666	9678	9678	9678	9678	9681	9711	9715	9742	10880	11210
33105007220000	2474	9652	9666	9667	9672	9675	9680	9681	9684	9684	9687	9717	9721	9750	10883	11211
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33105007420000	2301	10171	10185	10186	10188	10197	10201	10201	10201	10201	10208	10238	10241	10270	11475	11842
33105007450000	2513	9587	9598	9600	9603	9605	9619	9619	9619	9619	9626	9657	9661	9687		
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33105007820000	2317	9589	9600	9601	9610	9612	9616	9616	9616	9616	9621	9655	9658	9686	10924	11323
33105007890000	2033	9467	9482	9482	9487	9492	9495	9495	9495	9496	9504	9525	9527	9547	10710	11006
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33105008130000	2374	9530	9542	9542	9544	9551	9565	9565	9565	9565	9571	9599	9600	9628		
33105008140000	2011	9377	9392	9393	9400	9403	9405	9407	9409	9409	9413	9441	9442	9463	10650	10956
33105008200000	2324	9285	9296	9298	9301	9306	9316	9316	9316	9316	9320	9358	9359	9390	10645	11030
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33105008380000	2372	9737	9750	9753	9760	9768	9773	9773	9773	9773	9779	9809	9810	9841	11064	11441
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33105008500000	2466	9625	9639	9639	9640	9647	9656	9656	9656	9656	9659	9697	9699	9727		
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33105009530000	2163	9251	9266	9267	9273	9280	9280	9280	9280	9280	9285	9313	9314	9334	10510	10844
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33105009830000	2381	9403	9414	9415	9418	9422	9436	9436	9436	9436	9441	9480	9482	9515		
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33105009960000	2363	9896	9908	9909	9916	9919	9923	9925	9928	9928	9934	9969	9971	10001	11213	11611
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33105010050000	2413	9524	9536	9539	9549	9554	9560	9560	9560	9560	9564	9595	9597	9626	10793	11124
33105010110000	2073	9113	9123	9124	9130	9132	9140	9140	9140	9140	9145	9163	9165	9178	10336	10610
33105010150000	2248	9212	9226	9227	9235	9238	9241	9241	9241	9241	9245	9271	9273	9291	10495	10814
33105010250000	2448	9524	9536	9536	9538	9544	9554	9554	9554	9554	9559	9597	9599	9627	10789	11152
33105010380000	2377	9491	9502	9504	9509	9511	9525	9525	9525	9525	9531	9560	9561	9590	10752	11184
33105010450000	2479	9596	9608	9609	9613	9620	9628	9629	9628	9629	9636	9667	9668	9698	10854	11193
33105010520000	2349	9468	9480	9481	9486	9490	9502	9502	9502	9502	9510	9539	9540	9567	10732	11083
33105010530000	2030	9585	9598	9599	9603	9611	9611	9611	9611	9611	9615	9643	9643	9662	10836	11143
33105010570000	2322	9426	9436	9437	9443	9447	9460	9460	9460	9459	9463	9493	9495	9522	10689	11027
33105010590000	2347	9450	9460	9462	9467	9471	9483	9483	9483	9483	9491	9519	9520	9548	10714	11025
33105010620000	2458	9541	9551	9553	9557	9559	9575	9575	9575	9575	9579	9611	9613	9642	10808	11135
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33105010780000	2319	9389	9400	9403	9410	9416	9424	9424	9424	9424	9430	9457	9458	9486	10686	11035
33105010800000	2338	9383	9394	9395	9401	9404	9420	9420	9420	9419	9433	9455	9456	9486	10666	11010
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33105010890000	2334	9383	9397	9398	9404	9409	9418	9418	9418	9418	9428	9459	9460	9492	10676	11016
33105010900000	2404	9495	9507	9507	9508	9514	9530	9530	9531	9530	9536	9567	9568	9597	10759	11087
33105010940000	2430	9526	9536	9537	9541	9545	9558	9558	9558	9558	9565	9595	9596	9624	10783	11105
33105010950000	2192	9298	9311	9313	9320	9332	9332	9332	9332	9332	9338	9357	9359	9380	10566	10894
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33105011120000	2328	9367	9378	9379	9384	9388				9402	9413	9438	9439	9467	10670	11022
33105011130000	2249	9854	9869	9869	9871	9874	9883	9883	9883	9883	9889	9925	9927	9952	11175	11555
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UWI/API	Datm	BKKN	MB10	MB_9	MB_8	MB_7	MB_6	MB_5	MB_4	MB_3	MB_2	MB_1	L_SH	TRFK	PRVP	WPGS
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33105011270000	2336	9207	9218	9219	9229	9234	9247	9247	9247	9247	9251	9278	9283	9312		
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33105011430000	2481	9621	9633	9633	9635	9641	9651	9651	9651	9651	9655	9689	9691	9719	10850	11180
33105011640000	2444	10030	10043	10045	10051	10054	10057	10057	10057	10057	10062	10085	10087	10103	11216	11523
33105011680000	2391	9407	9417	9419	9428	9433	9439	9439	9439	9439	9443	9476	9478	9507	10696	11020
33105011690000	2347	9418	9429	9431	9441	9448	9451	9451	9451	9451	9465	9486	9488	9516	10678	11010
33105011730000	2434	9608	9622	9621	9623	9628	9640	9640	9640	9639	9644	9677	9679	9705	10831	11170
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33105012170000	2372	9427	9447	9449	9455	9458	9473	9473	9473	9473	9484	9516	9517	9550	10725	10990
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33105013220000	2329	9323	9335	9337	9345	9352	9355	9355	9355	9355	9360	9396	9398	9430	10675	11066
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33105015650000	2516	9610	9622	9623	9625	9629	9640	9640	9640	9640	9651	9681	9682	9710	10864	11220
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33105016630000	2443	9532	9545	9546	9551	9555	9564	9564	9564	9564	9573	9604	9606	9634	10817	11188
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25091210490000	2220														10594	10834
25091210550000	2196	8332	8343	8344	8355	8359	8365	8365	8365	8365	8371	8391	8393	8412	9578	9854
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25091211640000	2255	7790	7798	7799	7811	7815	7822	7823	7825	7825	7829	7852	7855	7874		
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25091211890000	2008	8622	8631	8634	8643	8646	8651	8651	8651	8651	8656	8673	8674	8685		
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25091211970000	2110	9290	9301	9301	9310	9314	9317	9317	9317	9317	9323	9337	9340	9349		
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25091212030000	2053	8520	8530	8531	8545	8548	8554	8554	8554	8554	8560	8584	8586	8609	9798	10096
25091212060000	2189	9456	9469	9470	9474	9477	9483	9483	9483	9483	9486	9505	9507	9520	10605	10790
25091212100000	1998	8773	8783	8786	8795	8798	8801	8801	8801	8801	8806	8823	8826	8835	9927	10169
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25091212280000	2010	8770	8779	8782	8791	8794	8797	8797	8797	8797	8806	8819	8821	8830		
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25091212630000	2059	8881	8890	8893	8900	8904	8912	8912	8912	8912	8916	8934	8935	8945		
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25091212730000	2040	8877	8887	8888	8897	8901	8905	8904	8905	8904	8913	8929	8930	8940		
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25091213160000	2177	8511	8521	8522	8534	8537	8543	8543	8543	8543	8546	8570	8571	8587	9711	9991
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25091213530000	2004	8842	8852	8854	8862	8865	8870	8870	8870	8870	8874	8896	8898	8906	9996	10239
25091213560000	2103	8746	8755	8758	8766	8770	8774	8774	8774	8774	8780	8800	8801	8811		
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25091213830000	2194	7667	7676	7678	7691	7694	7698	7700	7702	7702	7705	7734	7736	7757		
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25091214040000	2214	8640	8649	8650	8662	8666	8670	8670	8670	8670	8678	8695	8696	8709	9846	10127
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25091214360000	2106	9402	9414	9415	9420		9429	9429	9429	9428	9432	9450	9451	9462	10566	10820
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25091214490000	2184	8765	8775	8776	8788	8797	8797	8797	8797	8797	8799	8822	8823	8834		
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25091214570000	1987	8885	8894	8897	8905	8909	8912	8912	8912	8912	8919	8935	8936	8947		
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25091215480000	2108	7782	7790	7792	7804	7807	7810	7811	7811	7811	7816	7842	7843	7862	9080	9384
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25091215530000	2008	8882	8893	8895	8902	8906	8909	8910	8910	8909	8918	8934	8935	8945	10050	10299
25091215580000	2163	9383	9396	9396	9405		9411	9411	9411	9411	9417	9432	9433	9443	10536	10776
25091215590000	2017	8746	8757	8761	8769	8773	8776	8776	8776	8776	8780	8802	8802	8815	9969	10256
25091215600000	2426	8167	8177	8180	8191	8194	8200	8200	8200	8200	8208	8230	8232	8250	9434	9724
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25091215760000	2272	8721	8731	8732	8744	8747	8753	8753	8753	8753	8759	8779	8780	8793	9942	10202
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25091216000000	1991	8846	8856	8857	8868	8872	8876	8876	8876	8876	8883	8899	8900	8909	10016	10278
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25091216190000	2020	8675	8685	8688	8697	8700	8703	8703	8703	8703	8712	8724	8726	8737	9846	10170
25091216240000	2073	8506	8518	8519	8532	8535	8542	8542	8542	8542	8548	8572	8573	8595	9768	10042
25091216250000	2054	8554	8566	8567	8579	8583	8588	8588	8588	8588	8595	8622	8623	8645	9819	10114
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25091216420000	2233	9604	9616	9617	9624	9627	9629	9629	9629	9629	9632	9650	9651	9663	10750	11009
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25091216480000	2263	8133	8142	8143	8149	8153	8167	8167	8167	8167	8172	8196	8197	8216	9400	9688
25091216500000	2468	8483	8496	8497	8507	8512	8521	8521	8521	8521	8528	8553	8555	8574	9852	9970
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25091216530000	2307	8173	8185	8186	8198	8201	8205	8205	8205	8205	8212	8235	8236	8254	9446	9743
25091216580000	2122	8182	8192	8193	8202	8205	8214	8214	8214	8214	8222	8245	8246	8268	9450	9691
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25091217800000	2247															
25091217830000	2301															
25091217990000	2206															
25091218090000	2060														10490	10716
25091218250000	2294															
25091218280000	2350															
25091218310000	2077															
25091218340000	0														9858	10120
25091218380000	2344														9801	10053
25091218400000	2133															
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25091218530000	2312														9143	9435
25091218550000	2259														10798	11065
25091218630000	2062															
25091218670000	2503														9502	9806

UWI/API	Datm	BKKN	MB10	MB_9	MB_8	MB_7	MB_6	MB_5	MB_4	MB_3	MB_2	MB_1	L_SH	TRFK	PRVP	WPGS
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Canadian Wells			
UWI/API	Datum	PRVP	WPGS
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101011400117W200	2268		9070
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101020800314W200	2027.9		
101021400116W200	2309.1		
101022200216W200	2297.9	8776	8942
101022500110W200	1905.5		
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101031600210W200	1918	8327	8809
101031800313W200	1989.5		
101031800313W202	1989.5		
101032000216W200	2338.9	8712	8992
101041900217W200	2444.9		
101050600208W200	1886.5	8251	8530
101051400209W200	1877	8147	8550
101053000115W200	2323.2	8984	9220
101060200214W200	2236.2		
101073000115W200	2327.1		
101080500214W200	2231	8796	9101
101082200217W200	2341.9		
101093400215W200	2173.9		
101101500116W200	2301.8		
101101500116W202	2301.8		
101101500116W203	2301.8		
101101500116W204	2301.8		
101101600214W200	2123	8629	8858
101101600214W202	2123	8629	8858
101101600214W203	2123		
101102500115W200	2257.9	8848	9150
101111400209W200	1874	8134	8516
101112500113W202	2065		
101112700117W200	2309.1		9010
101112700117W202	2309.1		9010
101112700117W203	2309.1		9010
101112700117W204	2309.1		9010
101121200213W200	1961.9	8483	8827
101121400116W200	2336		
101121400116W202	2336		
101122100116W200	2251		
101122700106W200	1869		
101130300115W200	2240.2		
101131800314W200	2009.2		
101132300117W200	2261.2		9010
101142500118W200	2341.9		
101150700308W200	1922.9	7910	8400
101150900214W200	2154.9	8655	
101151400218W200	2413.1		
101160800215W202	2296.3		
101161600313W200	1981	8100	8450
101163600118W200	2371.1		8911
111012100114W200	2279.5		
111012100114W202	2279.5		
111042300209W200	1871.1	8097	8501
111051400209W200	1874.3	8143	8542
111052800106W200	1851.7		
111081900214W200	2122.4		
111082200209W200	1870.7	8102	8438
111092900106W202	1803.8		
111113000209W200	1877.3	8110	8497
111113000209W202	1877.3	8110	8497
111141500315W200	2149.3	8360	8596
111150500108W200	1914		9016
111161500209W200	1884.2	8144	8534
121031000315W200	2303.1		
121042300209W200	1870.4	8107	8434
121051300214W200	2071.5		
121062700209W200	1863.2	8036	8382
121072300117W200	2232.9		8999
121091000215W200	2249		
121091000215W202	2249		
121092200209W200	1870.4	8081	8422
121102800110W200	1926	8760	8958
121111600214W200	2134.5		

UWI/API	Datum	PRVP	WPGS
121113300216W200	2358.6		
121122400110W200	1907.8	8535	9008
121131800112W200	2073.2		
121150200310W200	1866.8	8018	8382
121152500115W200	2250.3		
121152500115W202	2250.3		
121160200215W200	2284.4		
121160200215W202	2284.4		
121160200215W203	2284.4		
121160200215W204	2284.4		
131012800209W200	1868.4	8072	8458
131031400310W200	1872	7953	8343
131033200116W200	2281.2		
131041600108W200	1900.6		
131043600210W200	1874.7	8092	8496
131050900106W200	1934.1		
131052900117W200	2383.2		9055
131052900117W202	2383.2		9055
131052900117W203	2383.2		
131081100109W200	1906.5		
131092100212W200	1961	8376	8732
131092100212W202	1960.6		8645
131120100206W200	1879.9		
131121300206W200	1890.1		
131123100117W200	2371.7		
131130300116W200	2271.3		
131131000107W200	1896.3		
131141400209W200	1876.6	8123	8496
131152500108W200	1879.3		
131152500210W200	1873.7	8088	8467
131152500210W202	1873.7	8089	
131161200112W200	1980.6		
131163200114W200	2245.7		
141012900212W200	1962.9		
141013200206W200	1915.4		
141030800111W200	1975.1	8809	9242
141051200118W200	2338.6		
141062300107W200	1879.3		
141062700209W200	1864.2	8044	8542
141062900117W200	2361.9		
141062900117W202	2361.9		
141062900117W203	2361.9		
141090500207W200	1833.3		
141090500306W200	1918		
141101000215W200	2252.9	8907	9199
141101000215W202	2252.9	8907	9199
141101000215W203	2252.9	8907	9199
141101000215W204	2252.9	8907	9199
141101000215W205	2252.9	8907	9199
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141151400117W200	2257.5		9021
141152800207W200	1919		
141153100109W200	1903.9		
141153100109W202	1903.9		
141153100109W203	1903.9		
141153100115W200	2329.4		
141153100115W202	2329.4		
141161000218W200	2433.4		
141161100106W200	1995.1		
150020800314W200	2039		8629

SIGNATURE PAGE

This is to certify that the thesis prepared by Mandy Brewer entitled "Geology of the middle member of the Bakken Formation in Divide County, North Dakota" has been examined and approved for acceptance by the Department of Geological Engineering, Montana Tech of The University of Montana, on this 15th day of November, 2018.

Larry Smith, PhD, Associate Professor and Department Head
Department of Geological Engineering
Chair, Examination Committee

Christopher Gammons, PhD, Professor
Department of Geological Engineering
Member, Examination Committee

David Reichhardt, Assistant Professor
Department of Petroleum Engineering
Member, Examination Committee